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COMPUTER SCIENCE SECTION

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ORIGINAL

SUMMARY OF AWARDS

Fiscal Year 1982

NATIONAL SCIENCE FOUNDATION
Directorate for
Mathematical and Physical Sciences
Division of
Mathematical and Computer Sciences
Computer Science Section
Washington, DC 20550

COMPUTER SCIENCE SECTION

SUMMARY OF AWARDS

Fiscal Year 1982

NATIONAL SCIENCE FOUNDATION
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Computer Science Section
Washington, DC 20550

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Preface

The purpose of this report is to provide the scientific community with a summary of those grants awarded by the Computer Science Section of the Division of Mathematical and Computer Sciences in Fiscal Year 1982. The report lists fewer than the actual number of projects currently receiving support because the duration of some grants exceeds one year.

Similar areas of research are grouped together for reader convenience. The reader is cautioned, however, not to assume these categories represent either the totality of interests of each program or the total scope of each grant. Projects may bridge several programs or deal with topics not explicitly mentioned herein. Thus, these categories have been assigned administratively and for the purposes of this report only.*

In this document, grantee institutions and principal investigators are identified first. Award identification numbers, award amounts, and award durations are enumerated after the individual project titles. Within each category, awards are listed alphabetically by state and institution.

Readers wishing further information on any particular project described in this report are advised to contact principal investigators directly.

Kent K. Curtis
Section Head
Computer Science Section

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* To get an idea of the scope of possible programs, consult ***What Can Be Automated? The Computer Science and Engineering Research Study*** (***COSERS***), Bruce Arden (Ed.), MIT Press, Cambridge, MA (1980).

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Introduction

This report provides summaries of awards made by the National Science Foundation (NSF) through the Computer Science Section in Fiscal Year 1982. In Fiscal Year 1982, Computer Science Section award activities were carried out through eight programs. Topics of interest to the Foundation include, but are not limited, to the following:

Computer Systems Design

Principles of computer systems design relating to the structure of computer systems or the process of systems design. Topics include, but are not limited to: computer system architecture; distributed computer systems; integrated hardware software systems; performance measurement and evaluation; fault tolerant systems; logic design; computer graphics; man-machine interaction; and VLSI design methodology. The scope of this program includes experimental implementation where that is an integral part of the research.

Intelligent Systems

Computer-based systems that have some of the characteristics of intelligence. Relevant areas of inquiry include: knowledge engineering; automated theorem-proving; mechanical inferencing; problem solving; pattern analysis; computer vision; natural language and speech understanding; and areas related to the automatic analysis and handling of complex tasks.

Software Engineering

The structure and design process of computer software, especially verification, testing, portability, reliability, and human interfacing to numeric and non-numeric software systems. Areas of emphasis include: program validation and testing; software tools; and human factors in software design and use. The program also supports research in computationally oriented numerical analysis, the design and construction of high quality portable software for scientific research, and experimental implementation where that is an integral part of the research.

Software Systems Science

Conceptual basis for the specification of future software systems and the necessary experimentation with such systems, including: advanced programming languages and optimizing compilers; functional and relational specification program transforming systems; systems for the verification and proof of correctness of programs; the study of the concurrency of operations; the discovery of new algorithms and improved measures of effectiveness of known algorithms.

Special Projects

New directions in computer science and applications including computer networks; database management; computer-based modeling; privacy and security of computer systems; and other topics of special interest in computer science.

Theoretical Computer Science

Theories of computation and formal languages; analysis of algorithms; theoretical models for computation; and other theoretical problems concerned with the foundations of computer science.

Computer Research Equipment

Support of special purpose equipment needed by more than one computer research project and difficult to justify on a single project.

Coordinated Experimental Research

Experimental Computer Research—The establishment and enhancement of experimental research facilities, needed technical and professional support personnel, and necessary maintenance of facilities; large multi-investigator projects in experimental computer research (5 year awards expected).

New Faculty Investigators in Experimental Research—Establish creative research programs for new faculty with high potential for research in experimental computer science by relieving them partially of the usual obligations of a heavy teaching load and committee work during the initial period of their academic careers (no new awards expected).

Computer Science Research Network (CSNET)—Build a logical computer-based communication network spanning ARPANET, public packet networks, and PHONENET, a telephone-based relay system; provide communication services, file transfer, and access to remote databases; stimulate new classes of network research activities.

Additional Information

For additional information on any of the projects, contact the principal investigators directly.

Division of Mathematical and Computer Sciences

E. F. Infante
Division Director
(202) 357-9669

Computer Science Section

Kent K. Curtis
Section Head
(202) 357-9747

Program or Area	*Program Director*	*Telephone*
Computational Mathematics	Bruce H. Barnes	(202) 357-7345
Computer Research Equipment	John R. Lehmann	(202) 357-7349
Computer Systems Design	John R. Lehmann	(202) 357-7349
Coordinated Experimental Research	W. Richards Adrion	(202) 357-7375
CSNET	W. Richards Adrion	(202) 357-7375
Intelligent Systems	Y. T. Chien	(202) 357-7345
Software Engineering	Bruce H. Barnes	(202) 357-7345
Software Systems Science	Thomas A. Keenan	(202) 357-7375
Special Projects	W. Richards Adrion	(202) 357-7375
Theoretical Computer Science	John C. Cherniavsky	(202) 357-7349

November 1982

Summary

	Number of Projects	Value of Awards
Computational Mathematics	22	$884,830
Computer Systems Design	34	$2,698,530
VLSI Design Methodology	3	219,655
Computer System Architecture	15	1,182,620
Fault Tolerance and Reliability	3	314,459
Computer System Performance Measurement and Evaluation	8	447,585
Computer Graphics	5	534,211
Intelligent Systems	48	$2,906,939
Computer Vision and Image Processing	13	712,223
Natural Language and Signal Understanding	11	686,395
Automatic Theorem Proving, Concept Learning, and Inference	9	511,252
Knowledge Representation and Problem Solving	15	997,069
Software Engineering	35	$1,963,678
Quality Software	8	450,390
Symbolic and Algebraic Manipulation	3	7,101
Software Studies and Metrics	6	216,746
Program Testing and Verification	5	279,409
Software Tools and Programming Environments	13	920,032
Software Systems Science	36	$3,067,051
Programming Languages: Design, Semantics, Implementation	12	939,272
Operating Systems and Concurrency	4	222,827
Data Bases	2	178,848
Programming Methodology	12	1,108,109
Distributed Computing	4	442,299
Verification	2	175,696
Special Projects	20	$1,154,645
Data Handling, Data Manipulation, Database Research	4	271,735
Privacy & Security	3	34,079
The Societal Impact of Computing	4	381,930
Modelling & Simulation	1	76,829
Networking, Computer Communications, & Distributed Computing	1	32,000
Other Projects, Symposia, Colloquia, and Studies	7	258,072
Theoretical Computer Science	71	$3,150,813
Concrete Complexity and Analysis of Algorithms	40	1,867,556
Parallel, Distributed, and Data Base Models	9	442,051
Foundations of Computer Science	10	555,351
Automata and Language-based Models	12	285,855

Computer Research Equipment	13	$1,212,724
Coordinated Experimental Research	20	$8,551,495
Experimental Computer Research	10	7,097,974
New Faculty Investigators in Experimental Research	4	246,292
Computer Science Research Network (CSNET)	6	1,207,229
Small Business Innovation Research	6	

Note: The above amounts are those supported by the Computer Science Section and do not reflect the total of the awards. Refer to the individual summaries for details.

Computational Mathematics

Stanford University; Gene H. Golub, James Wilkinson, and Germund Dahlquist; *Numerical Linear Algebra*; (MCS-7811985 A05); $119,965; 12 mos.

This research involves investigations into a number of areas in numerical linear algebra. These include the generalized algebraic eigenvalue problem, updating techniques for matrix factorization, the inverse eigenvalue problem and solutions of sparse systems of linear equations. During all of these studies there will be an emphasis on the development of high quality numerical algorithms which take advantage of recent developments in computer technology.

University of Southern California; Wlodek Proskurowski; *Fast Numerical Methods for Solving the Helmholtz Equation and Related Problems*; (MCS-8003382 A01); $27,657; 24 mos.

This project is for research on efficient numerical methods for solving linear and nonlinear partial differential equations with the Helmholtz operator in arbitrary bounded planar regions. Capacitance matrix techniques provide the tool with which this goal can be achieved. The intent is to upgrade the performance of existing mathematical software as well as extend it. A study of new methods based on the variational principle, will be conducted. Efficient interative schemes for solving certain types of nonlinear PDEs and problems with nonlinear boundary conditions will be developed.

Colorado State University; Patricia M. Prenter; *Adaptive and Non-Adaptive Data Compression with Applications to Radiometric Remote Sensing (Computer/Atmospheric Research)*; (MCS-8201875); $27,409; 24 mos. (Joint support with the Global Atmospheric Research Program-Total Grant $54,809).

Ongoing research of the principal investigators on adaptive and nonadaptive data compression schemes will be continued. Special emphasis will be placed on the application of these schemes to radiometric remote sensing with the intent of improving upon extant statistical inversion algorithms for first kind noisy nonlinear integral equations and their ability to effectively predict atmospheric vapor, liquid and temperature profiles. Real data from the NOAA, ERL, Boulder, Colorado, will be used in testing the effectiveness of these schemes.

Applications to the general problem of sparse, high-information content signal processing and to economic archiving and implementation of such data will also be purused.

University of Colorado-Boulder; Richard H. Byrd; *Trust Region Methods for Minimization*; (MCS-8115475 A01); $40,120; 12 mos.

This project involves the development, analysis, and testing of new algorithms for unconstrained and constrained minimization, with particular emphasis on algorithms using trust regions. There are four main topics: 1) Develop algorithms using rectangular trust regions, in the hope that they will offer advantages over ellipsoidal trust regions, especially in such applications as linearly constrained minimization and successive quadratic programming for nonlinearly constrained minimization. 2) Use prescriptive trust regions in minimization algorithms using majorizing quadratic models. This should enable us to produce significantly faster algorithms for specific classes of problems. 3) Continuation of our research on minimization algorithms using conic models of the objective function, which so far appears to be a very promising area. Many new aspects are suggested, including another new use of trust regions. 4) Continuation of our research in indefinite linearly constrained minimization, especially considering trust region strategies and strategies for dropping active constraints.

In addition, a new algorithm for augmenting a symmetric matrix to be positive definite that has application to many of these topics will be developed.

University of Colorado-Boulder; Karl E. Gustafson (In colaboration with David P. Young, Boeing Computer Services); *Industry/University Cooperative Research: Computational Studies and Software Development in Hydrodynamics, Concentration Diffusion Equations, and Chemical Kinetics*; (MCS-8012220 A01); $31,073; 12 mos. (Joint support with the Industry/University Cooperative Program-Total Grant $62,459).

Computational studies and software development will be performed for problems in three-dimensional hydrodynamics, concentration-diffusion equations, and chemical kinetics. This work will be carried out on a cooperative university-industry joint-work basis at the University of Colorado and the Boeing Laboratories. These studies play a role in the understanding of the onset of instabilities in hydrodynamics leading to turbulence, flow of substances and mixed concentrations through porous media, and in bifurcation theory for thermal ignition, combustion problems, and rapid chemical mixing.

University of Illinois-Urbana; Ahmed Sameh; ***Parallel Numerical Algorithms***; (MCS-8117010); $49,202; 12 mos.

The goal of this research is the development of high speed and high quality synchronous parallel numerical algorithms. These algorithms primarily concern: (l) solving sparse symmetric and nonsymmetric systems of linear equations that arise from the finite difference or finite element discretization of partial differential equations, and (2) solving sparse linear least squares problems in geodesy and image reconstruction. In designing these algorithms we specify the simplest configuraion of the processor interconnection network that ensures high speedup without making the algorithm communication intensive. Furthermore, an automatic error analysis package will be used to check and compare the stability of these algorithms.

University of Illinois-Urbana; Robert Skeel; ***Error Estimation and Control for Numerical Solution of Stiff Differential Equations:*** (MCS-8107046); $24,455; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $48,910).

Professor Skeel plans to determine good computational techniques for obtaining estimates of the local error in computer codes for solving stiff ordinary differential equations as well as estimates of the global error in the computed solution. Local error estimates are used by codes to select the stepsize and the formula and are needed for deferred correction estimates of the global error. The asymptotic basis for current techniques is not valid for stiff problems. Professor Skeel also plans to determine an appropriate stepsize control strategy for stiff problems, which takes into account the fact that the work per step varies depending on the number of corrector iterations.

Purdue University; Walter Gautschi; ***Applied Orthogonal Polynomials***; (MCS-7927158 A01); $27,766; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $42,766).

The numerical solution of boundary value problems, singular integral equations, conformal mapping problems, and multiple integration problems often calls for the evaluation of one-dimensional integrals that involve a weight function. Effective tools for computing such integrals are the quadrature rules of Gauss, Radau, and Lobatto type. The object of this study is to develop constructive methods for generating these quadrature rules and to provide appropriate mathematical software. It is expected that the results of this research will stimulate the employment of these advanced integration schemes in applications such as those mentioned above.

University of Iowa; Kendall E. Atkinson; ***Integral Equation Methods for the Solution of Laplace's Equation*** (***Mathematical Sciences***); (MCS-8002422 A01); $6,000; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $34,500).

Integral equation methods are becoming widely used for the solution of Laplace's equation and other related equations. Support is sought for the continuation of several projects for the numerical solution of Laplace's equation in two and three dimensions, using integral equation reformulations. These projects include (l) an improved theoretical understanding of collocation methods for integral equations arising on regions whose boundary is only piecewise smooth; (2) development of a library of portable computer routines for solving interior and exterior problems in three dimensions for regions with smooth boundary; (3) the theoretical analysis and practical implementation of a quadratic isoparametric method for three-dimensional regions with only a piecewise smooth boundary and (4) methods for the Poisson equation. This continues work initiated under MCS-8002422.

University of Maryland-Baltimore County; Arthur G. Werschulz; ***Analytic Computational Complexity*** (***Computer Research***); (MCS-8203271); $10,000; 24 mos.(Joint support with the Theoretical Computer Science Program-Total Grant $25,852).

Analytic computational complexity is that area of applied mathematics and theoretical computer science which seeks to determine the minimal cost of solving a given class of problems, the problem class having the property that no finite-cost algorithms exist for its exact solution. The Investigator's previous research has mainly been in this area, covering problems in numerical quadrature, differentiation, and the solution of differential equations, as well as the solution of general abstract problems. The Investigator is studying a number of new problems in this area, such as the effect of model of computation on the quadrature problem, the removal of certain restrictions (e.g., zero boundary data) on elliptic boundary-value problems, the complexity of non-elliptic partial differential equations, more intensive study of optimality properties of finite-element methods, characterizing optimal-complexity functions, and the role of regularity in general Banach-space problems.

Massachusetts Institute of Technology; Jeremy F. Shapiro; *Lagrangean Techniques for Parametric Mixed Integer Programming*; (ECS-8117105); $49,307; 24 mos. (Joint support with the Systems Theory and Operations Research Program-Total Grant $98,614).

This research is concerned with theoretical and computational studies into new integer programming parametric methods based on Lagrangean relaxation. Four major research areas are identified and considered including approximation methods, right-hand-side parametrics, the relationship of Lagrangean and duality methods, and the extension of these techniques to new models. The methods are investigated both analytically and computationally, and are demonstrated on models of industrial engineering importance including production/distribution planning, vehicle scheduling, and multi-item inventory control problems.

University of Minnesota; Judah Ben Rosen; *Global Optimization Methods for Linearly Constrained Large-Scale Problems*; (MCS-8101214 A01); $48,083; 12 mos.

The goal of this research is to develop efficient computational algorithms which find the global minimum of a concave function subject to linear constraints. The emphasis will be on methods suitable for large-scale problems where most of the variables appear only linearly in the objective function. In these methods, linear and nonlinear variables will be treated differently, so that the global solution of large, sparse problems can be obtained in a reasonable amount of time, provided only that the number of nonlinear variables is relatively small. It is also intended to produce an efficient and reliable software implementation of one or more of the best algorithms, and to thoroughly test such implementations on a variety of realistic problems.

This research represents a cooperative research effort between Professor J. B. Rosen of the University of Minnesota and Dr. E. H. McCall of Sperry-Univac.

Rutgers University; Michael D. Grigoriadis; *Coordinated Network Optimization System*; (MCS-8113503); $51,550; 12 mos.

This research involves the development and implementation of efficient algorithms for solving several classes of large, sparse network optimization problems. Investigation into how to best select and apply these algorithms for solving practical problems will be conducted. Rather than developing general-purpose algorithms for each class of network optimization problems, this approach will employ multiple algorithms, each directed to the most efficient treatment of a particular subclass. The identification of such subclasses of problems, the choice of the most appropriate algorithm and data structures, the generation of good solution strategies and the coordination of these tasks is a complex problem which has not been adequately studied.

City University of New York-City College; Donald Goldfarb; *Algorithms for Nonlinear Programming*; (MCS-8006065 A01); $58,550; 24 mos. (Joint support with the Applied Mathematics Program and the Systems Theory & Operations Research Program-Total Grant $88,550).

The purpose of this research is to develop, analyze, and test algorithms for nonlinear programming. Special emphasis will be placed upon the numerical stability of the algorithms and their ability to efficiently solve large sparse problems. As the ultimate goal of this research is the creation of effective and reliable software, implementational considerations will play an important role in the development as well as in the refinement of the algorithms. There are three classes of algorithms that will be investigated: successive quadratic programming algorithms for general nonlinear programs; ellipsoid and related algorithms for convex programs; and quadratic programming algorithms. Under the research opportunities for Small College Faculty Programs, Dr. Ashok Idnani will participate in this research.

Cornell University; Charles Van Loan; *Applied Matrix Computations*;(MCS-8004106 A01); $5,250; 0 mos.

The aim of this research is to adapt and extend some of the well-known algorithms in the matrix computation field to selected problems in control theory and statistics. These problems include (1) the algebraic Riccati equation, (2) the observability and controllability of linear systems, and (3) least squares fitting when errors are present in both the observations and the data. The algorithms to be developed will rely on orthogonal matrices and two benefits of the research are expected as a result: the development of reliable software and the construction of informative perturbation theories.

New York University; Olof Widlund; *Fast Methods for the Solution of Large Finite Difference and Finite Element Systems of Equations*; (MCS-8203236); $19,000; 12 mos. (Joint support with the Applied Mathematics Program-Total Grant $38,000).

This project is concerned with efficient methods of solving highly structured finite difference and finite element systems of equations. The further development of imbedding (capacitance matrix) and domain decomposition techniques for general finite element problems as well as for certain special, important equations defined on general bounded regions, uniformly triangulated in the interior will be investigated. One goal is a full extension of a mathematical framework to conforming finite elements for fourth order problems and to methods of mixed type. Of equal importance is continued work on improved handling of the geometry and the triangulation of general regions, the automatic design of Fast Poisson solvers for higher order elliptic finite element methods etc, and the extension and improvement of existing software. Further research is also planned on conjugate gradient type methods with a particular emphasis on nonsymmetric, symmetric indefinite and special nonlinear problems.

Pennsylvania State University; Jesse L. Barlow; *Probabilistic Error Analysis of Algorithms from Numerical Linear Algebra for Floating Point Computers*; (MCS-8201065); $31,000; 24 mos.

The goal of this research is to provide a solution to the unsolved problem of the probability distribution of roundoff errors in floating point addition and subtraction, and to apply the results to large scale matrix calculations by establishing confidence bounds for the errors of appropriate algorithms. The research will focus upon, but not be limited to, the probabilistic roundoff error analysis of algorithms for solving the weighted least squares problem and the algebraic eigenvalue problem on floating point computers.

Temple University; Richard M. Heiberger; *Robustness of Algorithms for Regression and Analysis of Variance*; (MCS-8200398); $19,060; 24 mos.

Regression and Analysis of Variance (ANOVA) are two statistical techniques heavily used by researchers in all scientific fields. Both are frequently used in data situations where unambiguous interpretation of their results is not possible. This occurs for ANOVA when there are unobserved cells in the cross-classification or the underlying error distribution is not normal, and for regression when the observed values of some variables are not available for analysis.

The work continues an investigation into the behavior of algorithms when used on data with missing cells or missing values. It is centered on studying the many oft-used, but not well understood, ad hoc procedures which have been developed, but whose performance characterisitcs and operating limits are unknown.

University of Pittsburgh; Werner C. Rheinboldt; *Computational Continuation Processes for the Solution of Nonlinear Systems of Equations*; (MCS-7805299 A04); $52,901; 12 mos.

This research program concerns the development and analysis of adaptive computational continuation algorithms considered, in a broad sense, as the collection of all methods necessary for a computational analysis of specified parts of the solution field of equations of the form $F = b$ where $f : R^m \rightarrow R^n$ is a given mapping and $m > n$. Some of the topics to be addressed are the detailed analysis of classes of predictor-continuation methods and the design of efficient step controls for them; investigation of the use of incremental formulations to compute or approximate the derivative of F; studies of numerical methods for bifurcation problems; design and analysis of adaptive parameter change algorithms, and their incorporation into the continuation processes; investigation of the influence of input changes upon the location of the limit points; general stability studies of the problems and methods considered; and last but not least the development of complete prototype programs for the analysis of solution fields and their use in an experimental assessment of the merits of the various methods and approaches.

University of Texas-Austin; David Young and David Kincaid; *Research and Development of Iterative Algorithms and Software for Elliptic Partial Differential Equations*; (MCS-7919829 A02); $49,300; 12 mos. (Joint support with the Applied Mathematics Program-Total Grant $65,843).

This project involves research and development of iterative algorithms and software for solving large systems of linear algebraic equations with sparse matrices. Particular emphasis will be placed on linear systems arising from the numerical solution of elliptic partial differential equations.

The work will have two aspects, namely, development of research-oriented software and research on iterative algorithms. The first aspect of the work will involve a substantial expansion of the capability of the ITPACK package to include more powerful iterative algorithms and to allow for handling more general classes of linear systems including systems with nonsymmetric matrices. It will also involve continued participation in the ELLPACK project. The second aspect of the work is closely related to the first and involves research on iterative algorithms with emphasis on effective methods for solving nonsymmetric linear problems.

Virginia Polytechnic Institute and State University; Layne T. Watson; *Mathematical Software for Homotopy Algorithms*; (MCS-8207217); $44,814; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $51,314).

In recent years homotopy algorithms have received widespread attention and much experience has now been obtained both theoretically and experimentally. However, recent conferences such as the June NATO Advanced Research Institute on Homotopy Methods and Global Convergence have pointed out that there is a need for high quality mathematical software in this area. The main goals of this research are to develop and distribute quality code for homotopy algorithms, after careful comparison and synthesis of existing research codes.

The investigator's primary objectives are:

1) To systematically compare and synthesize ODE based algorithms, normal flow methods, and augmented Jacobian methods;

2) To develop a quality general purpose homotopy curve tracking code;

The secondary objective is:

3) To carry out theoretical work extending the applicability of probability one homotopy methods.

University of Wisconsin-Madison; Olvi L. Mangasarian, Robert R. Meyer, and Stephen M. Robinson; ***Computation and Theory in Nonlinear Programming***; (MCS-8200632); $111,428; 12 mos.

The investigators will conduct research in the computational areas of successive overrelaxation (SOR) methods in mathematical programming, nonlinear programming, and equilibrium algorithms, nonlinear network algorithms, piecewise-linear approximation, exact penalty methods, parallel algorithms and algorithms for the complementarity problem and in the areas of nonlinear programming theory, generalized equations and stochastic programming. Computational testing of the algorithms developed will also be carried out on realistic problems in order to assess efficiently.

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Computer Systems Design

VLSI Design Methodology

Department of Defense; Robert S. Cooper; *NSF/DARPA Agreement for Use of DARPA VLSI Implementation Service*; (ECS-8210242); $50,000; 24 mos. (Joint Support with the Computer Engineering Program-Total Grant $100,000).

The development of technology making feasible Very Large Scale Integrated (VLSI) chips opens the way for universities to play a major innovative role in the design, construction, and application of novel special purpose hardware and new computer architectures. Considerable research is already in progress in the university community on software and hardware design tools needed to manage the complexity which arises in designing new VLSI computing structures containing tens of thousands of transitors on a silicon chip. Novel designs are being proposed and studied. There is a great need to implement these designs in silicon chips and test their performance.

A joint experiment over the next two years is being undertaken by the National Science Foundation and the Defense Advanced Research Projects Agency (DARPA) that will allow qualifying universities to use the DARPA fast turnaround VLSI implementation facility for university-based research and educational programs requiring the fabrication of digital designs as integrated circuit chips. As part of DARPA's research in the VLSI area they have developed a capability called "MOSIS" for fast turnaround implementation of VLSI chips. Designs submitted by DARPA researchers in digital form over the ARPANET or Telenet using standard design rules and a standard artwork format, known as CIF, are fabricated and returned to designers in about 4-6 weeks.

Access to this VLSI service by universities will be on a controlled basis with usage limited to those institutions that meet requirements jointly established by NSF and DARPA. The integrated circuit chips will be fabricated, packaged, and sent to the university groups submitting the designs as soon as possible.VLSI plays a major role in Computer Research.

Princeton University; Bruce W. Arden and David P. Dobkin; *VLSI Design and Testing Environment* (*Computer Research*); (MCS-8121851); $100,000; 24 mos. (Joint support with the Special Projects Program-Total Grant $249,150).

This award will aid in the establishment of an experimental facility to support a program of research in computer-aided, very large scale integrated (VLSI) circuit design, development, and testing. The facility will include powerful design workstations interconnected by a high bandwidth communications network.

The goal of the Princeton VLSI Project is to develop a total environment for the creation of VLSI circuits from design through testing to fabrication. Individual projects will be coordinated to insure that they contribute to an integrated environment. These projects include research in tools, techniques, and algorithms for circuit specification, circuit layout, and circuit verification.

The approach taken in the VLSI Project is based on a view that VLSI development is essentially a programming process. Research in circuit specification will build on the Census language and the census model developed by the investigators. The programming language, ALI, which is a Pascal extension will be the basis for further research into circuit layout techniques and aids. The research in circuit verification will emphasize validation of the translation process from high-level specification to actual circuit.

University of Wisconsin-Madison; James R. Goodman; *VLSI Implications on Computer Design* (*Computer Research*); (MCS-8202952); $69,655; 24 mos.

This research focuses on the exploitation of VLSI through the implementation of a full computer-CPU and memory-on a single integrated cirucit. Alternative ways to build a system with a limited amount of memory on the chip are being investigated. Three techniques are identified for reducing the off-chip communication: a memory hierarchy, efficient use of small memory, and innovative architectures. Each of these techniques shows the promise of very high performance systems within the constraints of VLSI.

Computer System Architecture

University of California-Berkeley; Chittoor V. Ramamoorthy; *Reducing Communication Costs in Distributed Systems*; (MCS-8107140); $58,000; 24 mos.

An important factor that reduces the efficiency of distributed processing is the high communication costs introduced during distributed processing. This high cost inhibits the exploitation of parallelism properties of applications and hence should be reduced to a minimum. The reduction may be achieved in two (inter-related) ways: (a) efficient implementation of the communication subsystem; (b) proper design of high-level algorithms which make use of the facilities provided by the communication subsystem.

This project focuses on the second aspect (b) including the development of a distributed computation model, and the analysis and design of distributed algorithms.

University of California-Irvine; Lubomir Bic; *Dataflow Databases (Computer Research)*; (MCS-8117516); $38,140; 24 mos.

This project focuses on the application of dataflow principles (functional, data-driven computation carried out by many asynchronous processing elements) to problems from the area of databases. Major objectives are to:

1. Utilize the inherent parallelism of dataflow processes capable of employing large numbers of processing units to provide increased database access bandwidth through concurrency in time and space. Dataflow models for for the relational database approach and the network (DBTG) approach are being explored.
2. Utilize the functional, side-effect free operation of dataflow processes to represent a semantic model of a database. Protection, semantic data integrity, and different user views of the database constitute central issues to be incorporated into the database model.

A computer architecture consisting of a large number of independent, asynchronously operating processing and memory units is envisioned as the underlying vehicle to support the proposed model.

University of Illinois-Urbana; David J. Kuck and Duncan Lawrie; *Computer System Organization*; (MCS-8001561 A02); $127,914; 12 mos.

This is a project aimed at moving forward the automation of computer system design on several levels. At the highest level, user Fortran programs are analyzed to obtain a rough idea of machine characteristics that are desirable for their efficient execution. The machines under consideration include those that execute single-array instructions, multiple-array instructions, and multiple-scalar instructions. Correspondences between program constructs and machine structures are measured by the analyzer. The analyzer may be thought of as a compiler prototype for these various machine structures. At the lowest level, the system can be used to accept behavioral descriptions of logic (e.g., sequential machine descriptions). The analyzer can take such a description, process it and map it into a structural description of the logic necessary to execute the behavioral description. As many technological constraints as possible will be incorporated to make this mapping realistic for VLSI circuit design.

University of Maryland; Yaohan Chu; *Concurrent Language Computer System Architecture*; (MCS-8205707); $88,259; 24 mos.

The focus of this research is on a new computer system architecture whose internal structure reflects the concurrent constructs of concurrent programming languages such as Concurrent Pascal, Modular, Modula-2, Ada & Edison. This architecture supports the direct execution of an operating system program written in a concurrent language rather than merely supporting some instructions to support concurrent languages.

Massachusetts Institute of Technology; Jack B. Dennis; *Data Flow Computer Architecture*; (MCS-7915255 A02); $98,955; 12 mos.

The Computation Structures Group is continuing its fundamental research on program structures and computer architecture for data flow computation. Areas being studied include: program transformations to better match program structure to a hypothetical data flow architecture; machine level program structure and code generation; hardware specification, verification and simulation based on an architecture description language for packet systems; and new methodologies for performance estimation and fault tolerance applicable to packet system architectures.

Northeastern University; Robert J. Lechner; *Harmonic Analysis of Logic Functions I: Encoded Programmable Logic Arrays (Computer Research)*; (MCS-8108685 A01); $18,293; 12

mos. (Joint support with the Theoretical Computer Science Program-Total Grant $36,587).

This research is concerned with the development and evaluation of a new unified approach to array logic synthesis using VLSI technology on a scale which applies to software storage as well as to firmware storage and wired control logic within digital systems. Specifically, PLAs are inbedded within linear encoding transformations on their inputs and outputs and combined with ROMS as necessary to define more optimal implementations of logic functions or stored tables than are possible with either ROMS or simple PLAs alone. In contrast to more general array logic techniques, the imbedded PLA approach retains the homogeneous array device layout and interconnection topology that reduces design and testing costs.

Heuristic algorithms are developed and tested on realistic examples to evaluate the feasability of the imbedded PLA approach. Theoretical studies are used to evaluate a more rigorous approach to canonical synthesis algorithms that do not require human intervention. A crucial outcome of the study is the identification of that class of functions for which the hybird (ROM+ imbedded PLA) approach to synthesis is more cost-effective than either ROMS or PLAs alone.

Michigan State University; P. David Fisher; *Multiprocessor Architectures for Enhanced Computational Capabilities of Single-Chip VLSI Microcomputers*; (MCS-7909216 A01); $$70,195; 24 mos.

This research is based on the premise that continued advances in integrated circuit fabrication technology will permit chip complexities to increase by at least tenfold over what they were at the end of 1980. The purpose of the research then is to investigate alternative single-chip microcomputer architectures that will exploit this technology to improve significantly the computational capabilities and general usefulness of small computer-based systems. The first task aims at the development of computational methodologies from which asynchronous data-dependent arithmetic algorithms can be modeled, simulated and analyzed. The second task focuses on the development of a data-driven computer model that executes these algorithms at the operation level. This model consists of a pair of "mirrored" trees, a buffering tree, and a distributing tree. Basically, it is a modified hourglass model with highly concurrent computing activities occurring at both leaf ends of the "mirrored" trees and with data communication taking place between them. The complexity of this data-flow structure is being assessed in the context of its application to both vector processing for on-line digital control and discrete-time filtering for real-time signal analysis.

University of Michigan; Daniel E. Atkins; *High-Performance, Application-Directed Arithmetic Processors*; (MCS-8007298 A02); $87,299; 12 mos.

The objective of this research is to establish theory and methodology relevant to the synthesis and analysis of high-performance digital computers which are optimized for a given application. Such special-purpose or application-directed machines can provide very cost-effective solutions (in some cases, the only solution) to important computational problems (e.g., real-time, 3-dimensional image processing, weather prediction, numerical wind tunnels).

Since arithmetic is fundamental to high-speed computing, a major component of the project relates to the creation of a computer-based Arithmetic Design System (ADS). This tool is assisting in the quantitative analysis of alternate approaches to implementing arithmetic processors including use of many novel number systems other than the predominant "two's complement". Major components of the ADS include time-space complexity analysis, numerical analysis, formal verification, automatic exploration of structural alternatives, simulation, and interface to computer-aided logic design. The ADS is being applied to design studies in the context of very large scale integrated (VLSI) circuit technology.The theory and methodolgy developed are being tested empirically by design and prototype construction of application-directed arithmetic processors.

Institute of Electrical & Electronic Engineers, Inc.; Jon T. Butler; *Group Travel for US Participants in the 12th International Symposium on Multiple-Valued Logic; Paris, France, May 25-27,1982*; (MCS-8121360); $5,700; 12 mos.

The 12th International Symposium on Multiple-Valued Logic will be held May 25-27, 1982 in Paris, France. Because of the interest in this subject in Europe, it is expected that many experts from that part of the world will contribute. This award provides support for 6 U.S. researchers to participate in this meeting and to benefit from the research results of European colleagues.

New York University; Jacob T. Schwartz; *The VLSI Software Architectures Laboratory Oriented Toward Large-Scale Parallelism*; (MCS-7921258 A02); $168,000; 12 mos. (Joint support with the Computer Engineering Program-Total Grant $249,000).

This project addresses one of the most significant opportunities being opened up by the rapid development of LSI (Large-Scale Integration) technology, namely the possibility of organizing parallel computation on a very large scale (e.g. using thousands of processors) especially for purposes of scientific and artificial-intelligence related computation. This program of research on algorithms, hardware architectures, and programming style is underway.

Duke University; Robert A. Wagner; *Boolean Vector Machine (Computer Research)*; (MCS-8202610); $119,188; 12 mos.

The Boolean Vector Machine (BVM) models the ability of today's computer technology to perform bit-wise parallel Boolean operations on huge vectors of zeros and ones. If a BVM's register or vector length is unrestricted, a BVM can solve efficiently (in polynomial time) many combinatorial problems which seem to require exponential time on conventional small-word-size computers. These same problems are of considerable importance, for if they can be solved efficiently in a given computational environment, then so also can several major problems of Artificial Intelligence and Combinatorial Optimization. The research described here seeks to determine the "value" of building a finite version of a BVM, one that costs roughly what a conventional computer of equal memory size would cost but that is capable of solving these combinatorial problems 2n/n times faster than the conventional machine, when both machines have n x 2n bits of memory.An essential part of the research endeavor is a design exercise, which will produce more or less detailed designs of the instruction set, interconnection network and packaging of one or more BVM systems. The performance of each of these systems on several different classes of problems will also be investigated, both in a pencil-paper exercise, where "time" is equated to "instructions executed", and in a real-time fashion.

The design exercise will also involve algorithm redesign, to execute efficiently on various BVM's. The development of new design methods for both hardware and software is an additional expected benefit from this work.

Pennsylvania State University; Don E. Heller; *Parallel Computations (Computer Research)*; (MCS-8202372); $65,550; 24 mos.

This research concerns parallel algorithms and VLSI processor arrays for matrix computations. The special purpose hardware design work consists of the investigation of the relatively untouched areas (in the context of VLSI) of sparse matrix manipulations and iterative methods for solution of linear equations and for eigenvalue and singular value computation. Part of the analysis is a consideration of tradeoffs between time, space and parallel processing power, to establish optimality of the designs. Certain questions of numerical analysis, prompted by the limitations of VLSI processor arrays, are being investigated. Since VLSI systems may be simulated on a parallel computer, results should indicate new ways in which to program these general purpose machines.

Southern Methodist University; David W. Matula; *Foundation of Finite Precision Arithmetic (Computer Research)*; (MCS-8012704 A02); $17,406; 12 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $34,813).

Advances in LSI and VLSI capabilities are fostering an era where complex special purpose hardware for specific application areas will be realizable at acceptable costs. The ability to represent all sufficiently simple fractions and to evaluate reasonably small rational expressions exactly are important features making fixed-slash and floating-slash arithmetic interesting possibilities for special purpose architectures. Previous research has demonstrated that fixed and floating-slash systems are sufficiently competitive in arithmetic logic design requirements and representation and timing efficiencies to be serious candidates for special purpose architectures. The research is directed toward developing and assessing the viability of these arithmetic systems in the most promising areas of application: specifically, (i) assessment of the growth of accumulated error in fixed-slash and floating-slash computations; (ii) investigation of the suitability of these systems for incorporation in symbolic computation packages; (iii) for micro and small minicomputer systems; an assessment of the ability of a single firmware level fixed-slash (or floating-slash) arithmetic package to support moderate user level exact integer, exact rational, and approximate real computation capability; and (iv) investigation of enhancements of particularly extended range for floating-slash and algorithms for special purpose functions such as square root.

University of Texas-Austin; James C. Browne; *High Performance Parallel Computing*; (MCS-8116099); $115,162; 12 mos.

This research project is an integrated experimental approach to parallel programming and parallel computing. It is driven by the mapping of significant computation problems to the Texas Reconfigurable Array Computer (TRAC). The purpose is to determine the applicability and effectiveness of a reconfigurable network architectured computer system as a vehicle for high performance parallel computing. The research includes design and development of basic software for a reconfigurable multiprocessor architecture, programming, execution and measurement of applications on TRAC and extension of the concept base of reconfigurable network architectured computing in the light of the knowledge developed by applications.

University of Utah; Lee A. Hollaar; *Continued Analysis and Development of Specialized Backend Processors for Very Large Text Databases*; (MCS-8021116 A01); $104,559; 12 mos.

This project continues work on the design and evaluation of specialized processors to support the efficient retrieval of information from a full text database. Two classes of processors have been investigated: index structure processors and text scanners. The performance of an index processor constructed of simple serial processors forming a binary tree has been determined, and its relationship to systems including text scanning hardware is evaluated.

A text scanner has been proposed using a new class of finite state automata (FSA) the Partitioned FSA(PFSA), which can be easily implemented as a VLSI circuit. The current research concentrates on three areas. The first is the development of a prototype PFSA text scanner to demonstrate its feasibility. This requires the construction and testing of the necessary integrated circuits and the development of satisfactory real-time query resolution algorithms. The second is the extension of the PFSA to add capabilities such as numeric range comparison and an inexact match capability to allow for inserted, deleted, transposed, or single incorrect characters. The performance of the PFSA and its memory requirements is also being determined for a wide variety of query types, and representative configurations for different classes of systems are being evaluated. The overall organization of a very large text database system implemented with index structure processors and text scanners is being examined.

Fault Tolerance and Reliability

Stanford University; Edward J. McCluskey; *Reliable Computers*; (MCS-8200129); $84,186; 12 mos.

This research is aimed at developing systematic design techniques for high-availability computer design. Specific attention will be given to unification of the treatment of: (1) production testing of integrated circuits and inclusion of appropriate circuitry to guarantee that this is economical (Design for Testability), (2) circuitry for concurrent checking of computer operation, and (3) system structure to facilitate restructuring to eliminate failed subsystems from interfering with correct operation.

The novelty of this study stems from the fact that all the aspects of high-availability computer design will be treated in a uniform way. Past studies of this topic have tended to emphasize one aspect of the problem to the exclusion of the others. Modern VLSI techniques make it possible to combine the various techniques into one unified design technique.

University of Southern California; Melvin A. Breuer; *Testing Methodologies for Complex Digital Systems*; (MCS-8203485); $122,964; 24 mos.

Two key aspects of digital VLSI circuits are being explored:

1. Testability measures. An indepth analysis of the known concepts of controllability and-observability, as well as a new concept called sensitivity is being carried out. The precise definitions of these concepts, as well as the relationship between these measures and circuit design style, test methodology, and design for testability are being explored. Aspects of the computation of these measures as well as necessary and sufficient conditions relating the values of these measures to circuit structure are being studied.
2. Test generation methods. The development of computationally efficient testing methods for very complex integrated circuits and the design of self-testing integrated circuits are being investigated.

University of Michigan-Ann Arbor; John P. Hayes; *Testing Methodologies for Complex Digital Systems*; (MCS-8213884); $107,309; 24 mos.

This project addresses two key aspects of the testing of digital VLSI circuits, namely testability specification and test generation methods. The emphasis of this research is on the development of computationally efficient techniques for testing complex integrated circuits. The relation between the design style of an integrated circuit and its testing requirements will be examined. Test generation procedures analogous to the D-Algorithm which are suitable for systems containing components of various complexity levels are being developed. A flexible algebraic notation (vector sequences) and high-level fault models are being used in this research. Regular interconnection structures for VLSI design are being studied with a view to identifying those that are easily testable a priori. The impact of design for testability on other circuit criteria like chip area and speed are also being considered. Current methods for designing self-testing integrated circuits are being surveyed and evaluated. The use of bit-slicing and related methods in the design of systems having a high degree of self-testability are being investigated.

Computer System Performance Measurement and Evaluation

Stanford University; Donald L. Iglehart (In Collaboration with Gerald S. Shedler, San Jose Research Laboratory, IBM); *Industry/University Cooperative Research: Simulation Output Analysis for Local Computer Networks*; (MCS-8203483); 49,157; 12 mos. (Joint support with the Industry/University Cooperative Program-Total Grant $98,314).

The focus of this research is on the development of rigorous theoretical foundations for discrete event digital simulation. Primary motivation for the specific work is the need for firmly based methods applicable to simulations of local computer networks. Emphasis is on the development of new probabilistic and statistical methods for the design of simulation experiments and the analysis of simulation output. The variability inherent in most local computer networks is such that to make meaningful performance predictions it is necessary to study the evolution of a stochatic system. Computer simulation is required to do the complexity of real systems. Once committed to computer simulation, theoretically sound and computationally efficient methods for carrying out the simulation must be found. Among the issues the simulator must face are the initial conditions for the system being simulated, the length of the simulation run, the number of replications of the experiements, and the length of the confidence interval. The estimation methods being studied rest on results from stochastic process theory.

University of Illinois-Urbana; Duncan H. Lawrie and J. Michael Randal; *Measurement and Analysis of File Usage and File Storage Hierarchy*; (MCS-8114762); $47,500; 24 mos.(Joint Support with the Software Engineering Program-Total Grant $95,000).

This proposal involves the investigation of the characteristics of file access processes in an interactive environment where fast access to a large number of files is critical to fulfill users' needs, and of the behavior of users toward a file storage hierarchy. The ultimate goal is to provide a body of theory, based on empirical measurement, which will allow effective management of file store hierarchies.

Over the past thirty months a uniquely extensive database of file and user activity in the slower levels of the hierarchy (disk, mass store, and user tapes) has been collected. This data will be used as a basis for the study.The Computing Services Office and Department of Computing Science are especially qualified to undertake this investigation. Both have considerable experience in measuring user behavior, the Computing Services Office has a CDC Mass Storage, and there has been more than two year's worth of data collected. This joint investigation will bring both theoretical and practical experience to bear upon this very important area.

University of Maryland; Ashok K. Agrawala; *Models for Routing and Software in Computer Systems*; (MCS-8112896); $91,984; 24 mos.

Two specific, but related, areas of centralized and distributed computer environments are being explored; 1) load sharing/routing, and 2) software modeling.

In the area of load sharing/routing, questions concerning efficient implementations of the virtual waiting time routing technique, optimal deterministic routing algorithms, and the extension of "threshold" loading disciplines to multiple servers which are not necessarily characterized by exponential holding times are being investigated.

In the area of software modeling, topics include the description of the use of systems in terms of software execution sequences which are then mapped onto hardware devices, and the development of class decomposition solution techniques for state dependent queuing network models.

Washington University; Mark Franklin; *Continuous Systems Simulation on Multiprocessor Systems (Computer Research)*; (MCS-7820731 A03); $40,000; 12 mos. (Joint support with the Special Projects Program-Total Grant $116,829).

The principal goal of this project is to increase significantly the solution speed and reduce the costs associated with continuous system simulation on computers. The principal vehicle for achieving this goal is the exploitation of multiple processor computer architecture, in particular architecture based on Very Large Scale Integration Technology (VLSI).

The research will be conducted in three main areas:

1. Algorithms, parallel integration methods and higher order numerical problems associated with simulation.
2. Systems architecture, quantifying hardware and software design parameters and system performance metrics.
3. Systems building and research tools development, development of systems workbench on which new ideas of structure and algorithms can be tried.

Vanderbilt University; Lawrence W. Dowdy; *Prediction Models for Computer System Performance*; (MCS-8203594); $64,540; 24 mos.

When a computer system upgrade is proposed, the question arises, "By how much is system performance likely to improve?" To answer this question, a base model of the current system is constructed. The model is validated against available measurement data. The validated model is then altered to reflect the proposed system upgrade. This altered base model is termed the prediction model. The performance of the prediction model is used as an estimate of actual performance of the upgraded system.

Two problems arise from this prediction scenario. The first problem is the validation of the base model. The required parameters for the base model are rarely all available from measurement tools. The unavailable parameters are estimated/calibrated-introducing errors. The second problem is the validation of the prediction model. Because of interdependencies among the parameters, traditional techniques of altering only the obvious parameters in obvious ways is a gross simplification. The interdependencies among the parameters need to be discovered and formalized.

This project focuses on both theoretical and experimental research in these two related problem areas: base model validation and prediction model validation. A measurement monitor is being constructed to obtain the needed parameters and to measure parameter interrelationships. The interrelationships are being abstracted and formalized. Performance prediction experiments are being constructed to test the applicability and accuracy of parameter dependency hypotheses.

Pacific Lutheran University; Richard J. Spillman; *Development and Analysis of a Testability Model for Digital Systems (Computer Research)*; (MCS-8205452); $25,178; 24 mos.

This research focuses on system testability employing a model which incorporates the best features of scorecard and algorithmic methods. Specifically, the objectives of this research are to:

1. Conduct a comparitive study of alternative testability meansures.
2. Develop a testability figure-of-merit (FOM) for use in system evaluation
3. Determine the impact of changes in system design on system testability.

University of Wisconsin-Madison; David J. Dewitt; *Evaluation of Database Machine Architectures*; (MCS-8201870); $76,486; 24 mos.

This project focuses on the design, evaluation, and implementation of multiprocessor organizations for enhancing the performance of relational database management systems. Research is continuing on the analysis of the architecture and the comparison with other database machine architectures using a model of an architecture implementing a dataflow database machine.Questions of concurrency control and recovery mechanisms for datebase machines, database machines for transaction processing systems, performance evaluation of VLSI chips for relational database operations, and the use of indexing in parallel algorithms for complex relational operations are being investigated.

University of Wisconsin-Madison; Charles R. Kime; *Testing and Diagnosis in VLSI Circuits and Systems (Computer Research)*; (MCS-8206564); $52,740; 12 mos.

Very-large-scale-integrated (VLSI) systems constitute an environment in which the problems of testing and fault location are becoming increasingly difficult as circuit densities and complexities increase. This research addresses two major problem areas: 1) built-in-test approaches for VLSI circuits and 2) fault location techniques for VLSI-based systems. The research in VLSI circuit testing focuses on test parallelism and scheduling, new approaches to exhaustive testing, alternative built-in test structures, analysis of linear data compression structures, fault location in circuits, and the relationship of built-in-test to structure design methodologies. The research in VLSI-based system fault location concentrates on built-in concepts at the system level, interconnection testing, distributed test control and response analysis, and the use of directed graph models for the analysis and design of diagnostics. This work attempts to provide systematic techniques for cost-effective solutions to portions of the VLSI testing problem which must be solved in order to effectively use VLSI technology.

Computer Graphics

Stanford University; Joseph Goodman and Albert Macovski; *Industry/University Cooperative Research: Three Dimensional Visualization of Computerized Tomography Images*; (ECS-7926432 A02); $30,867; 12 mos. (Joint support with the Automation, Bioengineering and Sensory Systems Program and the Industry/University Cooperative Program-Total Grant $185,207).

The general purpose of the work supported by this grant is to explore the possible use of holography as a means for displaying the three-dimensional data collected by a computerized tomography machine. Continued investigation of multiplex holography, multiple-exposure holography, and computer-generated holography is proposed.

Cornell University; Donald P. Greenberg; *Interactive Computer Graphics Input and Display Techniques*; (MCS-8203979); $200,000; 12 mos.

This research project is concerned with the development of new and improved input and display methods for interactive computer graphics. Two general areas are addressed, the graphical creation of geometric object descriptions, and algorithmic processes for realistic and dynamic image synthesis. Specific research topics include color science and equal perception spaces, a polygon hidden surface algorithm, a light reflection model, and investigations into new uses of coherence for high quality image display. Results are potentially useful to a full range of computer-aided-design applications.

Ohio State University; Franklin Crow; *Toward More Complicated Computer Imagery*; (MCS-7920977 A02); $47,462; 12 mos.

The realism and utility of computer generated shaded images is severely limited by the meager complexity of the scenes which can currently be handled. In an attempt to improve on this situation, a conventional scan-order hidden surface and display algorithm was extensively modified to enable images of 100 times greater complexity. Experience with these more complex images has reinforced the understanding of how much more complicated truly satisfactory images will have to be.

Hidden-surface algorithms currently in use are limited by sorting steps which require the presence of all data. The data describing scenes are defined inflexibly, making distant views computationally inefficent and closeups lacking in detail. In addition, the production of truly complicated images will require distributing the algorithms over many processors in order to make animated imagery cost effective. These highly interrelated problems are being explored by studying and implementing algorithms designed for concurrent processing environments and oriented to more intelligently defined shape descriptions.

Initial efforts will focus on the design of data structures to support efficient rendition of the same object at many different levels of detail. Subsequent work will focus on algorithms for the display of such objects which are designed for distributed execution. Finally, the algorithms will be implemented and image sequences produced on a multicomputer facility currently being acquired.

Ohio State University; Charles A. Csuri, and Karl Olson; *Complex Animation and Complex Object Synthesis*; (MCS-7923670 A02); $145,882; 12 mos.

This research concentrates on four tasks dealing with complex motion systems and complex object synthesis. The four research tasks are: complex motion specification and control, surface generation based upon skeleton representation, three-dimensional texture, and points as a graphics primitive.New algorithms are being developed to mathematically model complex motion systems. As a case study human motion has been selected because it involves parallel processes and it has great dynamic complexity and nonlinearity. Special purpose hardware will be designed and constructed to test these algorithms for real-time display. An interactive surface generation system is being implemented to create three-dimensional structures from skelton representations. Algorithms are being developed to simulate visual cues for 3-D surface detail.

An attempt will be made to use a portion of the DMAAC (Defense Mapping Agency) data base.

An investigation is being made of points as a graphics primitive. An analysis is being made of the data structure and animation requirements for use in displaying visual results from scientific models.

University of Utah; Richard F. Riesenfeld; *Subdivision Algorithms for Curved Surface Representation and Display* (*Computer Research*); (MCS-8203692); $110,000; 12 mos.

This project is concerned with the further investigation of subdivision algorithms and their generalizations as applied to computer aided geometric design. The Oslo Algorithm for computing discrete B-splines is a general structure for developing specific algorithms which are optimized and specialized for particular applications. Other work is being devoted to looking for non-tensor product surface formulations and analogues to the Oslo Algorithm. Such algorithms are being applied to designing set operations on freeform surfaces. Continued emphasis is being placed on combining high quality computer graphics and freeform surfaces.

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Intelligent Systems

Computer Vision
and Image Processing

Iowa State University; W. R. Madych; ***Summability Methods for Computed Tomography*** (***Mathematical Sciences***); (MCS-8282147); $26,000; 24 mos. (Joint support with the Applied Mathematics Program-Total Grant $52,000).

Computerized tomography is the study of certain aspects of the problem of reconstructing the interior of objects from certain types of data which can be obtained from measurements taken outside of these objects. The major mathematical problem in computerized tomography is the development of efficient algorithms.

Algorithms are procedures one applies to process the data in order to reconstruct the object. Many algorithms are known and several are in use in present day applications. Some of these algorithms give remarkable reconstructions. However, there are instances where the present techniques seem to break down; here we are referring to certain geometrical setups. One important case is the parallel beam model with nonuniformly spaced views, sometimes referred to as the limited angle problem. Such a problem arises, for example, when one cannot take X-rays which are uniformly spaced around 180 degrees.

As one of the projects in this proposal, the principal investigator proposes to study the limited angle problem with a view toward the development of efficient algorithms.

Johns Hopkins University; Joseph O'Rourke; ***Algorithms for Computer Vision***; (MCS-8117424); $63,558; 24 mos.

This research deals with three computational problems relevant to computer vision.

1. Improving the efficiency of the Hough transform, and in particular, applying it to motion detection and analysis.
2. Creation of polyhedral object models by surface area minimization.
3. Methods for decomposing polygons and polyhedra into simple parts.

All these problems are computationally complex, and their efficient solutions would be useful addition to the vision researcher's repertoire of techniques.

University of Maryland-College Park; Azriel Rosenfeld and Dianne P. O'Leary; ***Representation and Control in Computer Vision: Multilevel Relaxation Approaches*** (***Computer Research***); (MCS-7923422 A02 & A03); $129,073; 12 mos. (Joint support with the Automation, Bioengineering, & Sensing Systems Program-Total Grant $163,773).

Computer vision can be regarded as a process of establishing a correspondence between specific relational information derived from a scene and general relational information defining a model for a class of scenes. Computer vision systems make use of three types of data structures—arrays, region or object representations, and relational structures. In analyzing a given scene, information is discarded when passing from one representation to another. Multiple-resolution representations such as "pyramids" will be used to make this process more selective. They will also provide new ways of modeling shape and geometry, and of introducing information about them into the array-level processing.

The process of finding correspondences involves a potentially combinatorial search. Many "smart" search techniques exist, but parallelism provides the best possibility for speedup. "Relaxation" methods iteratively apply local constraints in parallel to reduce the size of the search space. Experiments on a variety of problems have shown that these methods are robust. A Bayesian basis for relaxation has recently been developed. Relaxation methods are being successfully extended to multiple, multilevel processes. The conditions under which these relaxation methods work are more fully understood as a result of these investigations.

University of Maryland; Azriel Rosenfeld; ***Workshop on Multiresolution Image Processing and Analysis-July 19-21, 1982 At Leesburg, Virginia***; (MCS-8205942); $22,998; 9 mos.

There has been a recent growth of interest in image processing and analysis techniques based on multiple-resolution representations of images. These techniques offer possiblilities for faster processing (log diameter time interactions among parts of an image), incorporation of global information and geometric knowledge into local processing, and smoother transitioning between pixel-level and region-level image representations. A three-day workshop will be held to review recent developments based on this approach and to identify areas in which further research is needed.

Massachusetts Institute of Technology; Whitman A. Richards; *Natural Computation and Control* (*Computer Research*); (MCS-7923110 A02); $165,716; 12 mos. (Joint support with the Division of Information Science & Technology and the Air Force Office of Scientific Research-Total Grant $445,716).

Research in natural computation explores the information processing mechanisms utilized by biological systems in performing basic sensory and motor functions. The MIT effort is primarily concerned with understanding the computational mechanisms which underlie the human visual system's representations of the external world. Topics to be investigated will include: (1) stereopsis, (2) texture, (3) structure from motion , (4) transparency, (5) color perception and normalization, and (6) derivation of object shape from contour and shading.

Michigan State University; Carl V. Page; *A Study of Augmented Relaxation Labeling for Parallel Image Understanding* (*Computer Research*); (MCS-8004126 A02); $40,000; 12 mos.

The theoretical concept of augmented relaxation process has been defined with the aid of practitioners of image understanding. A recent Ph.D thesis has extended this definition. Theoretical consequences of this definition will be studied with an eye to the development of parallel algorithms for image understanding. In particular, controlled processes which coordinate the interaction of global and local information will be studied by means of stochastic automata and stochastic languages. Key questions concern the generality of the methods, their stability and how amenable they are to parallel processing. A few experiments will be run on well-understood data to sharpen the definitions and verify results. A novel aspect of this work is that both top-down knowledge and bottom-up knowledge interact via a probability distribution over image descriptors.

University of Minnesota; William B. Thompson; *Disparity Analysis of Image Sequences* (*Computer Research*); (MCS-8105215 A01); $51,884; 12 mos.

Image sequences can provide important information about the three-dimensional structure and dynamic behavior of objects in a scene. Changes in a sequence can be characterized by disparity-the translation between frames of image points corresponding to particular points on the surface of visible objects. Disparity analysis encompasses methods for determining disparity values and inferring scene properties from those values. A study of disparity analysis with the intention of improving accuracy and efficiency, increasing the number of image points for which disparity values can be found, locating occlusion boundaries, and inferring depth relationships at those boundaries will be made. Improvements in disparity determination will come from better utilization of spatial context and from the temporal information available in longer sequences. The estimation of three-dimensional structure will be based on spatial variablity of disparity values and on the accretion and deletion of occluded surfaces across image sequences.

University of Rochester; Dana H. Ballard; *Parameter Nets: Towards A Theory of Low-Level Computer Vision*; (MCS-8203920); $66,869; 12 mos.

The goal of this research is to explain how parts of an image are perceived as a meaningful whole.

A stepping stone towards the solution of this problem is recent work which has shown how to calculate images of physical parameters from intensity data. Such images are known as intrinsic images, and examples are images of velocity (optical flow), surface orientation, occluding contour, and disparity. Intrinsic images show great promise but work needs to be done to specify their boundary conditions. They are distinctly easier to work with than the original intensity image, but they are not grouped into objects. This grouping can be detected by a general Hough transform technique which has the following aspects: possible objects are represented by networks of feature parameters: intrinsic image points are mapped into these object features. The Hough transform has been regarded as just another image processing technique, but recent and ongoing work at Rochester has shown that it is much more general. It is particularly resistant to occlusion and noise, and can specify intrinsic image boundaries.

These ideas are a nucleus of a connectionist theory of low-level and intermediate-level vision. This theory explains segmentation in terms of massively parallel cooperative computation among intrinsic images and a set of parameter spaces at different levels of abstraction.

Oregon State University; Kennan T. Smith; *Mathematical Aspects of Divergent Beam Radiography*; (MCS-8101586 A01):

$20,400; 12 mos. (Joint support with the Applied Mathematics Program-Total Grant 40,800).

The underlying objective of this project is the extraction of information from radiographs through the use of mathematics and mathematical thought. The research takes two separate but highly dependent directions.

The first is a mathematical study, usually rather sophisticated, of the nature of the information contained in a finite number of radiographs of an object. This involves also, as the limiting case of a large number of radiographs, the study of the information contained in a countably infinite number.

The second is the investigation of new methods of extracting information from radiographs and the improvement of known methods, such as computed tomography. In this part of the research the mathematics is sometimes sophisticated, as in the description of the general relation between point spread functions and convolution kernels in tomography; sometimes elementary, as in the work on mammography; and sometimes almost nonexistent, as in the work on noise elimination. But mathematical thought is always present, and experiments are crucial. The basic ideas come mainly from experiments, and from mathematical thought about them.

University of Pennsylvania; Ruzena K. Bajcsy; ***Strategies for Three-Dimensional Data Acquisition and Utilization*** (***Computer Research***); (MCS-8207294); $50,000; 12 mos.

This project seeks to investigate the use of different sensor systems to achieve a complex goal. The solution to the important problem of using visual and tactile sensors to acquire three-dimensional (3-D) data and to produce shape and size descriptions of objects is selected as the goal of this work. Each sensor system has particular operational requirements that govern its use. Also, the precision and accuracy of the data produced varies depending on the system. All sensor systems have their own individual strengths and weaknesses. The development of control strategies for using different sensor systems to produce results that transcend individual capabilities is one of the key tasks of this project. The results of this work should have applications in the developing areas of robotics, machine inspection and CAD/CAM.

University of Rhode Island; Robert B. Kelley; ***University/Industry Cooperative Research Center in Robotics***; (ISI-8203570); $5,000; 12 mos. (Joint support with Division of Industrial Science & Technological Innovation, Mechanical Systems Program, Office of Interdisciplinary Research, and Automation, Bioengineering & Sensing Systems Program-Total Grant $220,000).

Manufacturing represents approximately 25% of the gross national product; 75% of this is accounted for by less efficient batch production methods. Robotics is an emerging engineering technology which is expected to experience exceptional growth. It represents an area in which university research can develop a data base to foster rapid innovation in the manufacturing industries.

This 4-year continuing grant is funding the initiation of a University/Industry Cooperative Research Center in Robotics at the University of Rhode Island as an experiment in university/industry interaction. The center's research program, which is co-funded with industry, is focussing on integrated robot systems to develop a data base for industrial applications such as vision systems for robot control and inspection, integration of robotics into production systems, and articulated robotic hands with sensors.

Industrial support is providing approximately 75% of the cost for the first year of center operation. Industrial interaction and support is to increase each year to at least replace the decreasing National Science Foundation support and will totally fund the center after four years.

The University/Industry Cooperative Research Centers research program has a relatively high applied research component since the research program is cofunded with industry and is destined to become fully supported by industry within a 4 or 5 year period.

Virginia Polytechnic Institute and State University; Robert M. Haralick; ***Workshop on Computer Vision: Representation and Control: Franklin Pierce College, Rindge, New Hampshire, August 23-25, 1982***; (MCS-8211074); $6,800; 12 mos.

Computer Vision is a dominant area of current research. It is an area which must tie together what is known about image processing, the imaging physics, and artificial intelligence. This workshop will concenrate on the sharing of ideas which can help link these areas. Its format will not be that of a conference.

It will have some carefully chosen papers presented from among those submitted, but it will also have equal time for working groups of five or six people to get together to discuss and try to precisely define problems in their topic area and to suggest a course of future cooperative research.

There would be time for each group to make a small presentation to the entire workshop and a chance for several people who are well known researchers outside the computer vision mainstream to circulate in the small working groups and to offer their own insights there and to the entire workshop.

Virginia Polytechnic Institute and State University; Linda G. Shapiro and Robert M. Haralick; *Structural Matching and Geometric Reasoning for Object Classification*; (MCS-8102874 A01); $63,925; 12 mos.

This research plan for object classification from digital imagery consists of: 1) using the facet model for low level segmentation; 2) using sensing physics and domain specific knowledge to group raw segmented regions into meaningful surfaces; 3) using a relational data structure for representing both the two-dimensional image regions with their properties and the three-dimensional models of the various object types; 4) using a database that is organized into possibly overlapping clusters of three-dimensional object models, where objects in a single cluster have similar structure and similar attributes, and 5) using a combination of structural matching and geometric reasoning to determine which kind of objects having three-dimensional relational models in the database could have produced perspective projections that led to the two-dimensional relational structures extracted from the image.

The results of this research will be useful in automated assembly, automated inspection, and robot vision.

Natural Language and Signal Understanding

Stanford University; John R. Perry; *Computational Aspects of Situation Semantics (Computer Research)*; (MCS-8211902); $23,068; 24 mos. (Joint support with the Theoretical Computer Science and Information Science and Technology Programs-Total Grant $69,263).

Situation semantics is a mathematical theory of linguistic meaning that grew out of artificial intelligence work in natural language processing. The goals of research in situation semantics include developing computationally feasible procedures for natural language understanding systems, developing the mathematical theory of situation semantics, and comparing the efficiency of situation semantics to more standard approaches to the theory of linguistic meaning. This same research is being funded under MCS-8201940 to support Professor Perry's colleague and coworker, Professor Barwise, at the University of Wisconsin-Madison.

SRI International; Barbara J. Grosz; *A Problem-Solving Approach to the Design of Natural Language Utterances*; (MCS-8115105); $84,117; 12 mos.

This research addresses the problem of the specification of the information and processes involved in the generation of utterances in natural language. The major thesis of this work is that formal methods in problem solving, particularly planning methods, may be extended to operate at the level of the generation of surface linguistic forms. There are two major facets to the research. At the language level, linguistic and discourse goals and the actions available for achieving them must be identified and formalized. Concomitantly, current artificial intelligence methods in two areas, problem solving with multiple agents and common-sense reasoning about knowledge and action, must be adapted and extended to handle language-oriented operators. To enable testing this integrated approach to generation, these methods will be embodied in a computer system.

Purdue University; Leah J. Siegel and Howard J. Siegel; *Parallelism in Speech Processing*; (ECS-8120896); $40,000; 12 mos.(Joint support with the Computer Engineering Program-Total Grant, $80,266)

The objective of this research is to study the parallelism in speech processing tasks and how this parallelism can be exploited by large-scale multiprocessor systems. Both parallelism within a task and parallelism among tasks will be investigated for a variety of specific important speech processing problems. Algorithms based on the SIMD (single instruction stream-multiple data stream) and multiple-SIMD modes of parallelism will be developed and analyzed. A set of time complexity equations for evaluating the execution of a set of tasks on a partitioned multiple-SIMD system in terms of parameters such as the number of partitions, the size of the partitions, the time for intra- and inter-partition communications, and instruction speech will be derived. The features needed to express parallelism in a high level language for parallel speech processing will be evaluated. The design of highly parallel asynchronous architecture for speech understanding, based on the use of parallel subsystems to construct a virtual non-deterministic machine, will be explored. It will incorporate SIMD, multiple-SIMD, and special purpose processors as components.

This research will advance the state-of-the-art of both parallel processing and speech processing. It will aid researchers in these ares to exploit the parallelism of the large-scale multiprocessor computer systems of the 1980's.

Massachusetts Institute of Technology; Kenneth N. Stevens and Victor W. Zue; *Automatic Speech Understanding*; (MCS-8112899); $92,226; 12 mos.

The aim of this project is to compile and to analyze data on various acoustic-phonetic phenomena that occur in conversational speech in English. The data will be obtained from a large data base of English sentences that will be developed in collaboration with another organization (Bolt Beranek and Newman, Inc.). The acoustic-phonetic phenomena to be studied include: modification of vowels by nasalization, retrofexion, and lateralization of adjacent consonants; acoustic properties that mark times of release and implosion of consonants; characteristics of consonants in clusters; acoustic evidence for place of articulation of consonants in various phonetic environments; modification of characteristics of phonetic segments at word boundaries; and acoustic properties that mark word and phase boundaries. Based on these data, algorithms will be developed for identifying features of vowels and consonants occurring in these phonetic contexts, and these algorithms will be tested on utterances in the data base. The goal is to develop procedures for identifying linguistic units in running speech, and to indicate how these procedures can be applied in systems for automatic speech understanding.

Burroughs Corporation; Lynette Hirschman (In collaboration with Ralph Grishman, New York University); *Industry/University Cooperative Research: Robust Natural Language Parsing Using Graded Acceptability* (*Computer Research*); (MCS-8202397); $5,000; 12 mos; (Joint support with Industry/University Cooperative Research Program-Total Grant $9,206)

Current computer systems for natural language analysis typically fail to parse 10-20% of their input. Many of these sentences fail because the parser accepts only a "perfect" analysis, namely one that meets a whole set of detailed syntactic and semantic restrictions. The robustness of a natural language system would be considerably improved if the parser accepted the best available analysis, in case no "perfect" analysis were available. We propose to investigate two techniques for preferential parsing which would provide the parser with greater flexibility and robustness. The first technique is restriction relaxation. If the parser can not obtain a perfect analysis, it tries to obtain an analysis where one of a designated set of restrictions is allowed to fail. This technique will also be explored as a debugging aid, to identify the restriction blocking an analysis. The second technique to be investigated involves a weighting of alternative analyses, based on observed frequency occurrence of syntactic and semantic patterns in a parsed sample corpus. The results of parsing with restriction relaxation and parsing with weighting will be compared to the results of the current parsing algorithm. The use of weighting techniques to "tune" the parser to a new domain will also be investigated.

New York University; Ralph Grishman (In colaboration with Lynette Hirschman, Burroughs Corporation); *Industry/University Cooperative Research: Robust Natural Language Parsing Using Graded Acceptability* (*Computer Research*); (MCS-8202373); $50,000; 12 mos; (Joint support with Industry/University Cooperative Research Program-Total Grant $55,000)

Current computer systems for natural language analysis typically fail to parse 10-20% of their input. Many of these sentences fail because the parser accepts only a "perfect" analysis, namely one that meets a whole set of detailed syntactic and semantic restrictions. The robustness of a natural language system would be considerably improved if the parser accepted the best available analysis, in case no "perfect" analysis were available. We propose to investigate two techniques for preferential parsing which would provide the parser with greater flexibility and robustness. The first technique is restriction relaxation. If the parser can not obtain a perfect analysis, it tries to obtain an analysis where one of a designated set of restrictions is allowed to fail. This technique will also be explored as a debugging aid, to identify the restriction blocking an analysis. The second technique to be investigated involves a weighting of alternative analyses, based on observed frequency occurrence of syntactic and semantic patterns in a parsed sample corpus. The results of parsing with restriction relaxation and parsing with weighting will be compared to the results of the current parsing algorithm. The use of weighting techniques to "tune" the parser to a new domain will also be investigated.

University of Rochester; Steven L. Small; *Process and Message Structures for Distributed Natural Language Comprehension* (*Computer Research*); (MCS-8209971); $66,009; 24 mos.

This research involves the study of three designs for distributed natural language comprehension systems, which differ markedly along three dimensions. First is the extension of previous work on word-based parsing systems to include not only word expert processes, but expert processes for individual concepts and goals as well. These experts communicate in a small collection of symbol structures. The second design is intended for an ongoing research effort in dialogue modeling, and involves a few large modules interacting with predicate calculus assertion. The computing engines in this program will be quite large, and their interactions few. The third system architecture involves millions of computing units, each with several thousand connections to other units which communicate by transmitting activation. Comprehension takes place through the spreading of activation through the network of units. The research aims to determine the relative strengths and weaknesses of the different approaches for building distributed computer systems to understand natural languages.

Carnegie-Mellon University; Raj Reddy, Omer Akin and Ronald Cole; *Knowledge Acquisition and Knowledge Engineering in Speech Understanding* (*Computer Research*); (MCS-8205539); $141,209; 12 mos.

Although the area of automatic speech recognition has received increasing attention in recent years, there are still a number of unsolved problems that prevent the development of recognition systems that approximate human performance. Two of the most basic problems are the ability to perform speaker-independent recogniton and the ability to perform fine phonetic distinctions. Today's systems require substantial training to adapt to a new speaker, and are unable to deal with cofusable vocabularies. For example, the letters "B", "D", "P" and "T" cannot be recognized by most systems with better than 70% to 80% accuracy after training with a single speaker. Error rates of 20% to 30% are simply not good enough to achieve acceptable performance in natural task domains. In addition, adaptive techniques used in present systems are neither generalizable nor extensible to natural task domains. This research deals with a new methodology to find solutions to these problems. Specifically, knowledge acquisition and knowledge engineering techniques will be explored to develop automatic and interactive schemes for adapting a speech understanding system to new speakers, new words and new environments.

University of Pennsylvania; Aravind K. Joshi;*Research in Natural Language Processing* (*Computer Research*); (MCS-8107290 A01); $151,907; 12 mos.

This research project is concerned with several major areas in natural language processing dealing with several aspects of cooperative behavior in the context of question-answer systems, and addressing certain key issues in man-machine interactions through natural language. In particular, the project will investigate (1) cooperative responses for correcting misconceptions about the structure of the data base and for dealing with dynamic data bases, (2) the natural language generation of descriptions and explanations in question-answer systems, and (3) the role of mutual beliefs in question-answer systems. Other parts of the research deal with some issues in control of inferences and relationship of grammars to parsing strategies, both of which involve study of some formal systems.

University of Washington; Robert W. Ritchie ; *Toward Automated Natural Language Processing: Phrase Linking Grammars for Syntax and Semantics* (*Information Science*); (IST-8118393); $15,323; 12 mos. (Joint support with the Theoretical Computer Science and Information Science and Technology Programs-Total Grant $101,184).

This research project is focused on the characterization and understanding of natural language. An information structure called the "linked tree" is being used as a representation which will allow a syntactic and a semantic interpretation of natural language as well as the process of understanding natural language.

The investigators are particularly interested in the development of a restricted syntactic theory that is adequate to allow a revealing description of any natural language; and integration of semantics with syntax; a formulation of a theory of parsing and interpretation that is consistent with available psycholinguistic evidence; and insight into the exploitation of parallelism to study the complexity of language.

University of Wisconsin-Madison; K. Jon Barwise; *Computational Aspects of Situation Semantics* (*Computer Research*); (MCS-8201940); $17,536; 24 mos.(Joint support with the Theoretical Computer Science and Information Science and Technology Programs-Total Grant $52,609).

Situation semantics is a mathematical theory of linguistic meaning that grew out of artificial intelligence work in natural language processing. The goals of research in situation semantics include developing computationally feasible procedures for natural language understanding systems, developing the mathematical theory of situation semantics, and comparing the efficiency of situation semantics to more standard approaches to the theory of linguistic meaning. This same research is being funded under MCS-8211902 to support Professor Barwise's colleague and coworker, Professor Perry, at Stanford University.

Automatic Theorem Proving, Concept Learning, and Inference

Stanford University; John McCarthy; *Mechanical Theorem Proving and Development of EKL-An Interactive Proof Checking System (Computer Research)*; (MCS-8206565); $119,248; 12 mos.

The main tool in making a computer prove theorems or follow reasoning is an interactive proof checker. In this research this tool will be used to represent the facts involved in an intellectual problem and check that that representation is adequate to solve the problem. The development of such a tool will be based on an interactive proof-checker, called EKL.

The main distinguishing characteristic of EKL from other existing systems is its flexibility and adaptability to different mathematical environments. The emphasis will be on creating a system which would allow the expression and verification of mathematical facts to be made in a direct and natural way. The development of EKL will be heavily weighted in favor of expressibility and user friendliness as opposed to sophistication in decision procedures. The overall goal of this research, therefore, is to provide a friendly environment for formal manipulation.

Northern Illinois University; Ross A. Overbeek and Ewing Lusk; *Topics in Automated Theorem Proving (Computer Research)*; (MCS-8207496); $54,940; 12 mos.

This project is the continuation of an ongoing research in automated deduction. Since 1971 joint work between researchers at Argonne National Laboratory and Northern Illinois University has focused on the development of a powerful, useful program called AURA (AUtomated Reasoning Assistant). During the last three years this work has produced a number of results. A variety of open questions in ternary Boolean algebra, finite semigroups, equivalential calculus, and the design of digital circuits were answered using this system. Based on these results, additional efforts will be made to make the program more accessible and more user-oriented. These efforts will be the basis for a new program called LMA (Logic Machine Architecture), a multilayered implementation of software tools for the interactive creation of theorem proving systems.

The following are the goals of the project:

1. Continue to enhance the power and usefulness of both LMA and AURA.
2. Attempt to solve more open problems.
3. Prepare distribution materials for both LMA and AURA.

Northwestern University; Lawrence J. Henschen; *Automated Theorem Proving*; (MCS-7913252 A02); $52,494; 12 mos.

The objective of this research is to extend the theory of automated mathematical deduction using the formal language of mathematical logic. Two major problem areas will be investigated: (1) a new non-resolution technique involving the calculation of "covering terms" for determining the remaining permissible truth value assignments to clauses at each stage of the deduction; (2) incorporation of splitting rules for higher-order logic into the unification algorithm.

University of Illinois-Urbana; Ryszard S. Michalski; ***Studies in Computer Inductive Learning and Plausible Inference***; (MCS-8205166); $94,401; 12 mos.

This research is concerned with computer inductive learning and formal models of human plausible inference. It encompasses basic theoretical studies as well as the development of algorithms and their computer implementations and experimental applications to selected practical problems. Major topics of the research include:

1. Automated generation of derived descriptors (variables, relations, functions) which are most relevant for constructing inductive assertions.
2. The development of rules that govern the generalization processes and efficient strategies for their application in inductive inference.
3. The study and implementation of techniques for constructing conceptual hierarchies of objects.

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4. The development of experimental multi-purpose high performance inductive learning systems which incorporate the methodology for generating derived descriptors.
5. The application of inductive inference to the design of computer architectures and compiler structures.
6. The formalization of patterns of human plausible inference and an experimental computer implementation.

University of Maryland-College Park; Jack Minker; *Applications of Logic and Theorem Proving to Databases*; (MCS-7919418 A01); $12,052; 12 mos.

The major thrust of this research is the application of automated theorem proving and mathematical logic to database investigations. Three types will be treated: (1) theorem proving by linear resolution with unrestricted selection function using trees , (2) first-order logic and databases, and (3) database logic.

Database logic is a recently developed formalism whereby existing database systems can be viewed in terms of logic. It has the prospect of providing a unifying theoretical framework for database systems.

University of Michigan; Paul D. Scott; *A Novel Approach to Concept Learning Based on the Principles of Object-Oriented Languages* (*Computer Research*); (MCS-8203956); $39,920; 12 mos.

The objective of the research is to construct a system which is able to develop its own representation of a problem environment and use that representation to solve problems or achieve goals in that environment. This system will exhibit two forms of learning. The first of these underlies the process of building a representation of a novel environment. The system will form new 'concepts' in an attempt to classify the entities in its environment. The second form enables the system to solve problems in its enviroment. It involves the system discovering the consequences of its own actions on the environment.

Concept formation is achieved by a novel method which does not require any form of guidance from a human 'teacher'. The key idea is that entities are not classified on the basis of their observable properties but rather on the basis of what can be done to or with them. The observable properties merely serve to identify members of a class. The resulting internal organization resembles a representation written in an object-oriented programming language. The system represents its knowledge of the consequences of its own actions in the form of rules for constructing examples of particular classes.

State University of New York-Albany; Neil V. Murray; *An Investigation into the Design and Implementation of a Prawitz-Based Theorem Prover* (*Computer Research*); (MCS-8218331); $12,720; 12 mos.

The goal of this research is to design and implement a predicate calculus theorem prover which, although based on the same foundation (Herbrand's theorem) that underlies most predicate calculus provers, will possess several novel design characteristics. This theorem prover will not do inference per se, but will search directly for a contradictory set of instances of the input formulas, which are required to be quantifier-free but whose truth-functional structure is totally unrestricted. An unexplored variation of Prawitz analysis will be employed, in which the maximal unifiable partitions of the atoms of a set of formulas are surveyed.

Carnegie-Mellon University; Peter B. Andrews; *Automated Theorem Proving in Type Theory*; (MCS-8102870 A01); $44,112; 12 mos.

This research is directed toward enabling computers to construct and to check proofs of theorems of mathematics and other disciplines formalized in type theory (higher order logic) or first order logic, and to assist humans engaged in these tasks. Improvements will be made to an existing computer program which proves theorems by finding refutation matings embodying the essential logical structure of the theorems, and transforming the matings into natural deduction proofs. Matings induced by proofs will be studied, as a step toward a general theory of matings and proofs. Theory of matings will be extended from first to higher order logic.

Attempts will be made to design improved heuristics for constructing elegant proofs, and improved search strategies for finding refutation matings. Special attention will be paid to the problems of quantifier duplication and of avoiding redundant search induced by symmetries. It is hoped that theoretical insights into the structure of matings will yield heuristics for instantiating higher order variables, and that knowledge about solvable cases of the decision problem can be integrated into the program.

Development will continue on the computer system as a practical and convenient tool for constructing and checking proofs interactively or semi-automatically.

University of Texas-Austin; Woodrow W. Bledsoe; *Research on Automatic Theorem Proving and Applications*; (MCS-8011417 A01); $94,085; 12 mos.

This research is a continuation of present work in automatic theorem proving and its applications to program verification and mathematics. Earlier work has included the development of computer programs which: prove theorems as part of a program verification system; prove theorems from intermediate analysis with techniques for instantiating set variables and for handling general inequalities. Other work has been on complete sets of reducers and agenda driven provers. This investigation will continue the work, especially in program verification and complete sets of reducers, and in continuing the effort to build a more powerful general theorem prover.

Knowledge Representation and Problem Solving

Stanford University; Edward A. Feigenbaum; *The Automation of Scientific Inference: Heuristic Computing Applied to Protein Crystallography*; (MCS-8117330); $45,782; 12 mos.

The broad goal of this project is to develop intelligent computational systems that infer the three-dimensional structures of proteins from x-ray crystallographic data. CRYSALIS, an automated system for the interpretation of protein electron density maps, uses both formal and judgmental knowledge from experts to select appropriate procedures and to constrain the space of plausible protein structures. The hypothesis generating and testing procedures operate upon a variety of representations of the data, and work with several different descriptions of the structure being inferred. Consequently it has been necessary to design a highly flexible system, somewhat similar to the Hearsay-II speech understanding system, which permits a number of independent but cooperating knowledge sources to propose, augment and verify a solution to the problem as it is incrementally generated.

The research will be performed by computer scientists in the Heuristic Programming Project at Stanford University, in collaboration with crystallographers at Oak Ridge National Laboratories, crystallographers at the University of California at San Francisco, and the protein crystallography group at the University of California at San Diego. Direct support is provided only for the Stanford computer scientists. Computing will be carried out on the SUMEX-AIM facility located at the Stanford University Medical Center and the SCORE facility at the Stanford Computer Science Department. Collaborative groups will have access to the computer through a national computing network.

Stanford University; Edward A. Feigenbaum, Bruce Buchanan, Lawrence Kedes, and Douglas L. Brutlag; ***MOLGEN:** A Computer Science Application to Molecular Biology*; (ECS-8016247 A02); $44,273; 12 mos. (Joint support with the Computer Engineering Program and Biophysics Program-Total Grant $177,093).

The MOLGEN Program is a continuing collaboration between computer scientists and molecular biologists to develop computer methods for knowledge representation, symbolic inference, and other forms of advanced symbolic manipulation that are of importance to molecular genetics. A number of software packages have already been developed that are beginning to be widely used, and show great applications promise. The knowledge engineering techniques being developed in this project are applied to problems in synthetic molecular biology, specifically the cloning, sequence determination and analysis of biologically interesting regions of DNA. MOLGEN is a "software laboratory" in which to explore and test new concepts and methods of knowledge representation, knowledge base management and planning. The work under this grant significantly improves the extent and quality of the existing knowledge base in MOLGEN and introduces automatic methods for extending the knowledge base. These "learning" methods recognize when a MOLGEN generated plan for an experiment is worth preserving and then generalizes the plan appropriately so that it is useful over a wider class of situations than the one for exploring a wide range of questions of performance evaluation of applied intelligent systems. As intelligent systems science moves toward knowledge engineering, such questions take on increased significance for the design and test of future expert systems. Computer methods for assisting the planning of experiments also continue to be studied and developed. These involve experiment "debugging" and experiment plan optimization.

Stanford University; John McCarthy; *Basic Research in Artificial Intelligence*; (MCS-8104877 A01); $74,000; 12 mos.

The long range goal of this research is a program that can be told facts about the world and can use them effectively to achieve the goals it is given. More specifically, this research will emphasize the structure of formal reasoning, epistemological problems of artificial intelligence and mathematical theory of computation. The mathematical theory of computation supports the artificial intelligence work by providing tools for reasoning about complex strategies and showing that they attain their goals.

University of California-Los Angeles; Judea Pearl; *Studies in Heuristics*; (MCS-8114209); $53,164; 12 mos.

The primary objective of these studies is to continue the analytical investigations of the mathematical properties of heuristics and their influence on the performance of common search techniques. These include: quantifying the relations between the precision of the heuristic models used and the complexity of the search they help guide; comparisons of time-storage tradeoffs for various graph searching algorithms; procedures for comparing, improving, and combining heuristic functions; assessing the complexities and the quality of decisions of game-playing programs. In addition to these, new studies in the areas of mechanical generation of heuristics and the use of parallelism in graph searching will be initiated.

Yale University; Drew V. McDermott; *Spatial Reasoning for Problem Solving and Understanding* (*Computer Research*); (MCS-8203980); $88,680; 12 mos.

The goal of this project is to make reasoning about events in both space and time domain. In previous research, a model has been established to deal with concepts and knowledge about "fuzzy maps" which keep track of the approximate coordinates of objects with respect to several frames of reference. This research will extend the model in three ways: (1) to explore alternative kinds of coordinates that make it easier to assimilate information about closely packed objects; (2) to extend the use of fuzzy maps to capture temporal information by adding a temporal dimension to the spatial maps; (3) to use database techniques to store large fuzzy maps on secondary storage by examining how "data dependency" information can be characterized.

University of Maryland; Laveen N. Kanal and Dana S. Nau; *Unifying Approaches and Parallel Implementations for Search Algorithms in AI and Pattern Analysis*; (MCS-8117391); $112,120; 24 mos.

Search techniques have found wide use in almost all areas of computer science and engineering. Applications abound in such diverse areas as game playing, decision analysis, pattern recognition, robotics, and theorem proving. Research on problem solving search procedures and their applications in artificial intelligence and pattern recognition has been a continuing activity at the Laboratory for Pattern Analysis in the Department of Computer Science at the University of Maryland. A recent result of this research is a general Branch and Bound formulation for sequential and parallel minimax search of AND/OR graphs.

This research will further develop the general Branch and Bound formulation and investigate the conditions under which various specializations of this formulation are appropriate and effective. The differences and similarities among various classes of search procedures, e.g. state-space search, game tree search, problem reduction search, dynamic programming, and branch and bound, are not well understood. It now appears feasible to develop a general search model which would include these procedures as special cases, and make clear the relationships among them.

Massachusetts Institute of Technology; Gerald J. Sussman, Charles Rich and Richard C. Waters; *Abstraction, Inspection and Debugging in Programming*; (MCS-8117633); $61,647; 12 mos. (Joint support with the Software Engineering Program-Total Grant-$123,832).

Software Engineering has much to learn from other mature engineering disciplines because the problem solving behavior of engineers in different disciplines has many similarities. Three key ideas in current artificial intelligence theories of engineering problem solving are: (I) Abstraction-using a simplified view of the problem to guide the problem solving process. An example of using abstraction in programming is to first implement the desired behavior of a program on typical data before worrying about exception handling. (2) Inspection-problem solving by recognizing the form ("plan") of a solution. In programming, a plan may be a particular control strategy with unspecified primitive actions or an abstract data structure with an unspecified implementation. (3) Debugging-incremental modification of an almost satisfactory solution to a more satisfactory one. In programming, this evolution is triggered as often by a change in the problem specification as by an error in the initial solution. These three techniques are typically used together in a paradigm called AID (for Abstracting, Inspection, and Debugging). First an abstract model of the problem is constructed in which some important details are intentionally omitted. In this simplified view inspection methods are more likely to succeed, yielding the initial form of the solution. Further details of the problem are then added one at a time with corresponding incremental modifications to the solution. This project will investigate this model of program construction.

University of Massachusetts; Victor R. Lesser; *Cooperative Distributed Problem-Solving*; (MCS-8006327 A01); $86,993; 12 mos.

The major focus of this research is the exploration of a new model for distributed problem solving systems. The model's ability to handle the presence of inconsistent and incomplete information at the processing nodes will enhance the applicability of the distributed computing approach. The research effort will be directed at the development of:

1. Techniques for the measurement, diagnosis, simulation and mathematical analysis of distributed problem solving systems.
2. Mechanisms for distributed focus-of-control and planning.
3. Characterization of distributed algorithms in terms of the type of uncertainty in data and control they can resolve.
4. A distributed simulation facility using a color graphics display.

Wayne State University; Michael Conrad; *Development of Evolutionary Programming Techniques for Adaptive Information Processes* (*Computer Research*); (MCS-8205423); $54,362; 12 mos.

The progress which has been achieved in developing an adaptive pattern recognition algorithm in the context of the evolutionary selection circuits model of the brain is described. Extensive experimentation with the algorithm has shown that it is effective for solving pattern classification prblems and for model control problems, such as learning to hit a target in a specified amount of time under the influence of random forces. The algorithm will be enhanced by adding dynamic features which allow generalization and by adding a search enhancing technique known as the "genetic load" technique. It will be reprogrammed for greater efficiency and portability and put into a form which can accept a wider variety of problems. Aside from its connection to brain modeling, the algorithm is applicable to control devices for robots and for the efficient use of computational resources in highly parallel systems. Plans for applying the algorithm to prosthetic robotry as a paradigm practical problem of great importance are described. The algorithm and the organizational structure underlying its effectiveness have interesting cross-correlations to biochemical processes now known to play a controlling role in some neurons. A major part of the project research will involve further exploration of this cross-correlation.

Rutgers University; L. Thorne McCarty and Natesa S. Sridharan; *A Computational Theory of Legal Argument* (*Computer Research*); (MCS-8203591); $107,690; 12 mos; (Joint support with Law and Social Sciences Program-Total Grant $112,690)

This research is a continuation of the TAXMAN project, an experiment in the applications of artificial intelligence (AI) techniques to the study of legal reasoning and legal argumentation. In the previous study, a formal model of representation for legal concepts in terms of "prototypes" and "deformations" has been established. The current project is designed to extend this model to include heuristics and algorithms for the construction and modification of legal rules as well as concepts, and generalize it into a computational theory of legal argument. While the AI techniques explored in this research are for the specific knowledge domain of law, it is expected that the results will have consequences and applications in a variety of problem domains for which concepts, rules and procedures must be represented and manipulated in and by a computer system.

Rutgers University; Raymond Reiter; *Logical Foundations for the Representation of Incomplete Knowledge in Artificial Intelligence and Database Theory*; (MCS-8203954); $40,017; 12 mos.

A central problem for both Artificial Intelligence and Database Theory is that of representing incomplete information about the real world, and reasoning with this representation. This proposal addresses various aspects of this problem of incomplete knowledge, with emphasis on the following issues:

1. The closed world assumption and its relationship to circumscription.
2. A proof theory for a certain class of default theories and its relationship to the design of large parallel hardware semantic networks.
3. Query evaluation for relational databases with null values and disjunctive information.

Ohio State University; B. Chandrasekaran; ***Knowledge Organization and Problem Solving for Diagnostic Tasks* (*Computer Research*)**; (MCS-8103480 A01); $63,406; 12 mos.

An approach to knowledge organization and problem solving for expert systems which specialize in a certain class of tasks, viz., diagnosis will be investigated. The central ideas are: (l) knowledge is decomposed into a collection of specialists, each of whom concentrates in its knowledge about a relevant concept and (2) these conceptual specialists perform problem solving in parallel in certain specified ways, and use a blackboard as a record of the global state of problem solving. Several problems will be investigated including (l) how to coordinate the problem solving of lower level specialists, including deciding when to stop (2) development of a conceptual structure representation language which will make it easy to develop systems in different domains (3) study of temporal aspects of the diagnostic process and (4) multiple use of knowledge.

St. Joseph's University; Ranan B. Banerji ; ***Flexibility and Efficiency of Knowledge Representation in Intelligent Information Systems***; (MCS-8217964); $29,445; 12 mos. (Joint support with the Division of Information Science and Technology-Total Grant $58,889).

An intelligent information processing program requires a knowledge base. Programs to carry out a very specific task may have the knowledge incorporated in the program itself, while intelligent programs capable of handling a wide range of problems have their knowledge stored in a versatile, complex data structure which the program has to process. This entails a trade-off between the flexibility of a program and its efficiency: versatile programs tending to be less efficient.

The purpose of this research is to investigate as to how much of this trade-off is inherent and how much is avoidable. The initial phase will consist of comparing different available programs by embedding the structures of their data bases into one uniform structure of larger flexibility (symbolic logic or some restriction thereof). Studies will be made of question-answering and learning programs.

Brown University; Ulf Grenander and Walter Freiberger; ***A Theory Of Patterns And Its Applications* (*Computer Research*)**; (MCS-7924983 A02); $98,977; 12 mos.

This research is directed toward extending and completing the mathematical theory of regular structures (pattern theory) and applying this theory to specific problems in physics and biology. Application areas to be considered include: 1. the structure of scientific inference; 2. computer tomography; 3. image restoration; 4. biological growth models; 5. morphogenesis; 6. mathematical semantics; 7. social domination patterns; and 8. neural networks.

Virginia Polytechnic Institute and State University; John W. Roach; ***Coordinating Robot Arms* (*Computer Research*)**; (MCS-8210194); $65,958; 24 mos.

The research issues needed to build a multi-arm robot system are explored. The problem of integrating a number of independent processes to carry out tasks in parallel is discussed. Methods of representing and generating parallel plans are described and the mechanisms necessary for carrying out such plans are also described. The need for qualitative reasoning about forces, torques, and support is discussed as well as the need for finding methods of capturing cause and effect relationships. Robot arm control, the space intersection problem, and the use of visual sensory feedback are also discussed. It is suggested that an extension to the inferential language PROLOG be used to help integrate the entire system. Parts transfer, pick and place, and assembly operations will be the problems tackled using children's toys such as erector sets and tinker toys.

Software Engineering

Quality Software

University of Arizona; Webb C. Miller; *Toolpack at The University of Arizona, A Set of Software Tools*; (MCS-8210722); $52,317; 12 mos.

Toolpack is a systemized collection of software tools to facilitate the development and maintenance of Fortran programs. The collection will be a mechanism to promote the use of high quality tools in software engineerinng research and in the development of numerical software. The project is a collaborative effort among universities, government, and industry.

One of the three National Science Foundation awards that initiated the Toolpack project went to the University of California at Santa Barbara. The principal investigator of the UCSB grant is now located at the University of Arizona. This award is for funding the second and third of the projected three years of that award.

Support is requested to allow the principal investigator to carry out his duties as Toolpack Documentation Editor and to make the following three technical contributions to Toolpack: (1) the callgraph facility, (2) the structurer, and (3) the Fortran implementation of the command interpreter.

Stanford University; George B. Dantzig, Richard W. Cottle, and Walter Murray; *Computer Optimization of Complex Systems*; (MCS-7926009 A02); $126,002; 12 mos.

The Systems Optimization Laboratory (SOL), Department of Operations Research, Stanford University, is a center for research in mathematical programming and its applications. Research activities include both algorithmic development and model development with interaction between them, so as to reduce the gap which normally separates these two areas in practice. The topics of research include:

1. Efficient methods for large-scale "staircase" and other specially structured linear programs. Of particular interest are the continuous simplex approach, methods based on decomposition, and factorizations designed for staircase matrices.
2. Several refinements and extensions to the MINOS code for large-scale linearly constrained optimization.
3. Analysis of several topics in nonlinearly constrained optimization.
4. A study of Newton-type, sparse quasi Newton, and conjugate gradient methods for large, sparse, unconstrained optimization. It is anticipated that the results in the unconstrained case should suggest useful approaches to the large sub-problems that arise in constrained optimization.
5. Methods for large, sparse linear least squares, structured quadratic programs, and constrained linear and nonlinear least squares.
6. Evaluation and comparison of algorithms for various classes of optimization problems.

This work will also include an effort to collect sets of test problems that are non-trivial and representative.

University of California-Los Angeles; Thomas Liggett; *Statistics and Infinite Particle Systems*; (MCS-8002732 A04); $14,000; 12 mos. (Joint support with the Statistics & Probability Program-Total Grant $99,274).

Stone will investigate the asymtotic properties of procedures for nonparametric regression and classification and parametric model selection. Ferguson will work on computational aspects of Bayes decision rules with respect to priors which are mixtures of Dirichlet priors in certain nonparametric problems. Ylvisaker will work on interval estimates for the parameters of approximately linear models and the adaptation of these estimates to real data. Jennrich will study derivative free statistical algorithms and their application to covariance structure analysis. Liggett will work to develop and apply new monotonicity properties of spin systems, and will study new processes on noncompact spaces. Durrett will study the asymptotic distribution in time, stability of stationary distributions under small perturbations, and phase transitions for certain processes.

University of Colorado-Boulder; Leon Osterweil and Lloyd D. Fosdick; *TOOLPACK: University Of Colorado Participation*; (MCS-8000017 A02); $94,000; 12 mos.

TOOLPACK is a systematized collection of software tools to facilitate the development and maintenance of FORTRAN programs. The collection will be a mechanism to promote the use of high quality tools in software engineering research and in the development of numerical software. The project is a collaborative effort between universities, government and industry. The cooperating organizations are Argonne National Laboratories, Bell Laboratories, International Mathematical and Statistical Libraries, Inc. (IMSL), Jet Propulsion Laboratory, Numerical Algorithms Group (NAG), Purdue University, University of California, Santa Barbara and the University of Colorado.

Yale University; John A. Hartigan; *Clustering Algorithms (Computer/Statistics Research)*; (MCS-8102280 A01); $34, 599; 12 mos. (Joint support with the Statistics & Probability Program-Total Grant $57,599).

The goal of this project is the development, validation, coding and distribution of clustering algorithms.

Statistical properties of standard algorithms will be studied to prepare a basis for their evaluation and modification. Asymptotic behavior of the k-means technique has suggested a test for the presence of two or more clusters, and its behavior for many clusters in many dimensions will be studied. A theory of high density clustering suggests that single linkage is superior to the standard hierarchical techniques in detecting high density regions (or modes) in the data, but also that single linkage might be improved. Likelihood ratio tests for modes of densities carried by the minimum spanning tree (using maximum likelihood techniques for parameters constrained to lie in a partial order) suggest that improved clusters may be obtained by smoothing the minimum spanning tree adaptively. The asymptotic theory, empirical distributions of test statistics, and practical coding of minimum spanning tree smoothers will be undertaken. Work will continue on developing a statistical theory for block clustering, and for developing algorithms to construct block clusters from non-standard data structures.

Purdue University; John R. Rice; *Template Processors and TOOLPACK Evaluation*; (MCS-7926310 A02); $82,416; 12 mos.

TOOLPACK is a systematized collection of software tools to facilitate the development and maintenance of FORTRAN programs. The collection will be a mechanism to promote the use of high quality tools in software engineering research and in the development of numerical software. The project is a collaborative effort between universities, government and industry. The cooperating organizations are Argonne National Laboratories, Bell Laboratories, International Mathematical and Statistical Libraries, Inc. (IMSL), Jet Propulsion Laboratory, Numerical Algorithms Group (NAG), Purdue University, University of California, Santa Barbara and the University of Colorado.

Massachusetts Institute of Technology; Roy E. Welsch (In collaboration with David M. Gay, Bell Laboratories); *Industry/University Cooperative Research Project: Nonlinear Exponential-Family and Bounded-Influence Regression*; (MCS-8116778); $30,088; 12 mos. (Joint support with the Industry/University Cooperative Research Program-Total Grant $60,176).

This project is a collaborative effort with John E. Dennis, Jr. of Rice University and David M. Gay of Bell Laboratories on exploiting the structure present in a broad class of nonlinear regression problems. The research involves extending techniques that have proven worthwhile for nonlinear least squares to other members of the exponential family of regression problems and to nonlinear bounded-influence regression problems. These problems all have similiar structure: the Hessian (or Jacobian matrix) is the sum of two terms, one of which is readily available. It has proven worthwhile in the case of nonlinear least squares to approximate the remaining term by a quasi-Newton technique and to use an adaptive modeling strategy. This work aims to see how worthwhile such techniques are for these other regression problems. It also includes some research on handling simple bounds on the parameters in these regression problems and on computing covariances and other statistics. One major goal of this project is to write reliable, modular, semi-portable software for solving the various problems addressed.

Rice University; John E. Dennis (In collaboration with David M. Gay, Bell Laboratories); *Industry/University Cooperative Research Project: Nonlinear Exponential-Family and Bounded-Influence Regression (Industry/University Cooperative Research Project)*; (MCS-8116779); $16,968; 12 mos. (Joint support with the Industry/University Cooperative Research Program-Total Grant $33,936).

This project is a collaborative effort with David M. Gay of Bell Laboratories, and Roy E. Welsch of Massachusetts Institute of Technology on exploiting the structure present in a broad class of nonlinear regression problems. The research involves extending techniques that have proven worthwhile for nonlinear least squares to other members of the exponential family of regression problems and to nonlinear bounded-influence regression problems. These problems all have similar structure: the Hessian (or Jacobian matrix) is the sum of two terms, one of which is readily available. It has proven worthwhile in the case of nonlinear least squares to approximate the remaining term by a quasi-Newton technique and to use an adaptive modeling strategy. This work aims to see how worthwhile such techniques are for these other regression problems. It also includes some research on handling simple bounds on the parameters in these regression problems and on computing covariances and other statistics. One major goal of this project is to write reliable, modular, semi-portable software for solving the various problems addressed.

Symbolic and Algebraic Manipulation

University of Illinois-Chicago Circle; Vera Pless; *Computer Algorithms in Finite Groups and Combinatorial Structures*; (MCS-8201311); $11,100; 12 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $28,500).

This research is in the areas of error-correcting codes, computer algorithms, combinatorics, development of a group-theoretic and combinatorial computer system.

Pless will work on some difficult open cases of primes which can divide the group orders of certain extremal codes. She will investigate the theoretical aspects of "contracted codes", from a global point of view, and also the interconnections between projective geometries, designs, and self-dual codes. Leon will continue to develop algorithms for computing with groups and combinatorial structures, including graph isomorphism and automorphism algorithms, and prepare portable standard versions of several of his algorithms. He will work on the classification of 28-dimensional Hadamard matrices. He will investigate questions relating to the complexity of group-theoretic and combinatorial algorithms.

Leon and Pless will continue to improve their computer system CAMAC (a unified system for algebraic and combinatorial computation). They are adding new capabilities such as the computation of the automorphism group of Hadamard matrices and will incorporate programs to test whether 2 Hadamards or error-correcting codes are equivalent. They will continue to distribute CAMAC to potential uses. In addition, they are developing a Pascal CAMAC which will be easily transportable to most (including mini) computers, uses structured programming, and will handle graphs and designs as well as codes and groups.

Kent State University; Paul S. Wang; *Design and Implementation of Computer Algorithms for Symbolic Manipulation*; (MCS-8201239); $47,888; 24 mos.

This research program consists of the following four specific topics: (l) Extending current p-adic algorithms and programs to finite fields, rings and algebraic fields. (2) Algorithms and systems for mathematical manipulations over the complex plane. (3) Efficient representations and operations for symbolic matrices of special forms. (4) Integration of symbolic and numerical computational techniques.

The research when carried out will extend the frontiers of knowledge related to (1) efficient algorithms for exact symbolic mathematical computation involving p-adic algorithms, algorithms over the complex plane and the interface of symbolic and numerical programming systems and (2) the design and implementation of efficient software systems capable of performing many of these computations.

Kent State University; Michael Rothstein; *Algorithms for Indefinite Integration*; (MCS-8202671); $38,113; 24 mos.

This research program consists of the following two specific topics:

1. Improve the algorithms for integration proposed in 1976 by Risch and Norman and by Rothstein, by finding bounds which are easily computable, for the degrees of the subexpressions which can appear in the answer; or proving no bounds exist.
2. Search for algorithms for computing the integral in terms of special functions defined by integrals themselves.

University of Arizona; Gregory R. Andrews; *The Design and Analysis of Distributed Programs*; (MCS-8202869); $45,000; 24 mos. (Joint support with the Software Systems Science Program-Total Grant $197,521).

This project is concerned with the design and analysis of integrated distributed systems, which execute on and control a local network of processors.The focus of the project is on the nature of and relation between communication, concurrency, and robustness. The topics being addressed are: the semantics of distributed programming languages, language mechanisms for dealing with failures, programming techniques for achieving robustness, and analytic methods for evaluating distributed algorithms.

One of the goals is to use the technique of pools of servers to construct a working prototype of a network operating system that is implemented in the distributed programming language SR. The ultimate goal is to develop a deeper understanding of the semantics of distributed programming and the tradeoffs between concurrency, communication, and robustness.

University of Illinois-Urbana; Duncan H. Lawrie and J. Michael Randal; *Measurement and Analysis of File Usage and File Storage Hierarchy*; (MCS-8114762); $47,500; 24 mos. (Joint support with the Computer Systems Design Program-Total Grant $95,000).

This proposal involves the investigation of the characteristics of file access processes in an interactive environment where fast access to a large number of files is critical to fulfill users' needs, and of the behavior of users toward a file storage hierarchy. The ultimate goal is to provide a body of theory, based on empirical measurement, which will allow effective management of file storage hierarchies.

Over the past thirty months a uniquely extensive database of file and user activity in the slower levels of the hierarchy (disk, mass store, and user tapes) has been collected. This data will be used as a basis for the study.

The Computing Services Office and Department of Computing Science are especially qualified to undertake this investigation. Both have considerable experience in measuring user behavior, the Computing Services Office has a CDC Mass Storage, and there has been more than two year's worth of data collected. This joint investigation will bring both theoretical and practical experience to bear upon this very important area.

University of Massachusetts; Krithivas Ramamritham; *Resource Controllers for Distributed Systems*; (MCS-8202586); $61,383; 24 mos.

In the development of distributed systems, two important issues are the interactions among the different processes and the distribution and management of shared resources. Devoting one process to manage each shared resource limits the type of interactions between processes and paves the way for modular design of distributed systems. Obviously, shared resources and the processes that manage them play a critical role in the functioning of distributed systems.

This study is aimed at developing specification, design, and implementation techniques for distributed system software. The focus is on the processes that manage shared resources. Topics to be investigated include techniques for specifying the properties of shared resources and processes that share the resources as well as strategies for synthezing code for processes that manage the resources. In addition, techniques for verifying the correctness of extant mechanisms for resource management will be investigated in order to understand and develop the principles behind synthesis.

Temporal logic will be used as a formulism to provide framework for this invesitgation. By using the theory of temporal logic it is possible to treat both invariant and dynamic properties of software systems uniformly.

Michigan Technological University; Karl J. Ottenstein; *Program Translation for Parallel Systems* (*Computer Research*); (MCS-8203487); $35,000; 24 mos.

Computers are being designed and built which permit a high degree of concurrency. Some of these MIMD (multiple-instruction, multiple-data stream) architectures are control-driven in the conventional sense while others are data-driven—that is, instructions execute according to the availability of data. This project will investigate techniques for translating "conventional" languages (such as FORTRAN), having no special extensions for the expression of parallelism, into high-level or machine languages having those features. Average case complexity bounds for the designed transformations will be constructed based on data to be gathered and analyzed for data-dependency metrics.

Macalester College; G. Michael Schneider; *An Experimental Investigation of Novice/Expert Behavior in Program Comprehension* (*Computer Research*); (MCS-8216961); $27,863; 12 mos.

This research project will investigate the cognitive processes that come into play during an attempt to read and understand a program listing. Verbal protocols will be collected from a number of different subjects, and scored and analyzed in order to categorize the strategies and mental operations which are taking place. The questions to be answered are:

1. How is information extracted from the semantic syntactic construct of a program?
2. How are hypothesis about program behavior proposed and confirmed, and in what order?
3. Are the approaches of novices/experts significantly different? If so, in what way? and
4. Can we propose a general model of the program comprehension process?

Virginia Polytechnic Institute and State University; Dennis G. Kafura; *A Comprehensive Study of Software Metrics for Large-Scale Systems*; (MCS-8207110); $75,328; 24 mos.

Recent research has established a set of metrics which are particularly appropriate for large-scale systems. These metrics are based on two principles: (I) the connectivity of the system is the primary determinant of system structure, and (2) the information flow among components is the single best method to define the connectivity. Metrics based on this information flow concept are capable of determining "missing levels of abstraction", "stress points", "module complexity" and other important system properties. This research involves a series of extensions to the information flow metrics which build upon the basic research already completed. Four specific objectives are established which involve enhancements to the existing metrics, the development of measurement tools, comparison with other metrics and extensive validation experiments.

This is a joint project with Dr. Sallie Henry of the University of Wisconsin-La Crosse.

Program Testing & Verification

University of California-San Diego; William E. Howden; *Design Based Program Testing and Analysis (Computer Research)*; (MCS-8204243); $74,065; 24 mos.

This program of research is concerned with computer program testing and analysis methods which depend on the use of information in a program's design. The research is motivated by the results of two extensive empirical studies in which it was found that there is a significant number of program errors which are closely related to the design of a program and which can be detected using design based methods. The empirical studies indicate that many of these errors are of the more subtle and persistent kind.

The research will include an experiment using the design based functional testing methodology which is described in the appendices. It will also include research into design based static analysis. The most recent of the two motivating empirical studies indicated that one of the most troublesome classes of errors, missing code errors, can be successfully attacked using design based analysis mehtods that examine programs to see if certain classes of operations occur out of context or in the wrong sequence. The operations, their contexts, and the sequences in which they are allowed to occur can be described in appropriate design documentation. Research will be carried out both on techniques for representing and on methods for verifying the consistency of a program with this kind of design information.

University of Massachusetts; Steven J. Zeil; *Testbed for Evaluating Software Testing Methods*; (MCS-8210084); $39,917; 24 mos.

Although research into program testing has proposed a variety of possible testing methods, empirical study of these methods has been hampered by differences in scope among such methods and by the difficulty in finding a measure of testing effectiveness which would be both theoretically defensible and capable of providing distinguishing information about practical testing methods. A new measure which answers these objections is the size of the set of possible error expressions which a set of tests cannot possibly detect. The construction of a testbed system to derive these undetectable errors for FORTRAN programs is proposed.

This testbed will be employed to empirically study the relative power of a number of proposed testing strategies. The proposed measures will permit a more uniform evaluation of a wider range of testing strategies than has been possible in previous studies. Such an experiment should not only provide evidence of which methods are stronger, but also give some insight into what types of errors and program characteristics make testing more difficult.

University of Massachusetts; Lori A. Clarke and Debra J. Richardson; *A Partition Analysis Method to Demonstrate Program Reliability*; (MCS-8104202 A01); $42,924; 12 mos.

Program testing and program verification have long been considered unallied, competing approaches to demonstrating program reliability. Neither approach is infallible, yet they complement one another nicely. The partition analysis method integrates testing and verification in an attempt to counterbalance the weaknesses of each approach by the strength of the other. By analyzing the implementation and the specification of the problem, the method partitions the problem domain into procedure subdomains so that all elements of each subdomain are treated uniformly by the specification and processed uniformly by the implementation. The procedure subdomains provide the basis for the application of both verification and testing techniques.

This research includes the application of partition analysis to an extensive class of problems, the development of improvements to the methods, and studies of its effectiveness for demonstrating program reliability.

New York University; Martin Davis and Elaine J. Weyuker; *Theoretical Investigations in Computer Science*; (MCS-8201167); $70,000; 24 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $115,000).

This research includes continuing work on improved algorithms for the satisfiability problem, a problem that has played a central role in computational logic and in the theory of complexity of algorithms. Workers in artifical intelligence have introduced non-monotonic systems of logic intended to model aspects of everyday human inference not covered by classical logic. It is planned to investigate relations between semantic and proof-theoretic aspects of such systems. Interesting theoretical problems arise in attempts to gain insight into the question of what constitutes an "adequate" set of data for testinig a computer program before it is released for general use. Continued work seeks axiomatic characterizations of adequacy and studies the properties of one notion of adequacy based on program length. This last notion leads to a lower bound on the amount of data needed to test a given program.

University of Texas-Dallas; Simeon C. Ntafos; ***Required Element Testing** (**Computer Research**)*; (MCS-8003322 A02); $52,503; 24 mos.

Program testing remains the most widely used method for gaining confidence on the reliability of software. Most of the testing strategies fall into three categories: structural, black box and error seeding strategies. They respectively emphasize testing the program structure, the input specification and for certain types of errors. Required element testing is a flexible strategy that consists of specifying a set of required elements for a program (i.e., features that we want tested) and developing test cases to cover these elements. Data flow analysis has been used to specify the required elements with promising initial results. The goal of this research is to develop improved required element testing strategies and evaluate their effectiveness.

Software Tools and Programming Environments

University of Arizona; Eugene W. Myers; *The Design and Analysis of a Practical and Precise Interprocedural Data Flow Analysis System*; (MCS-8210096); $49,852; 24 mos.

Recently a number of results have appeared which present the theoretic foundation needed for the construction of precise interprocedural data flow analyzers. These methods have not yet appeared in practice as their feasibility and practicality have not been demonstrated. This research will provide the necessary empirical evidence and practical refinements. A prototype system for the PASCAL language will be constructed. A theoretic study into the semantic models that a priori have efficient solutions will be carried out.

University of Arizona; Ralph E. Griswold; ***High-Level Programming Language Facilities For Data Structure Processing***; (MCS-8101916 A01 & A02); $86,391; 12 mos.

This project involves the investigation of high-level programming language facilities for processing strings and structures.

Previous work has concentrated on two efforts: (1) the design of new facilities for characterizing and processing nonnumerical data, and (2) the implementation of these facilities so that they can be evaluated and made available to the computing community. There is a close interaction between these two efforts: the value of new facilities often can be determined only by their application to real problems. Conversely, the use of new facilities frequently suggests new possibilitites and neglected areas of application.

This research will build on past results and focus on three areas of investigation: (1) goal-directed expression evaluation and control structures that are needed for processing complex data structures, (2) high-level string processing facilities, including extension of present concepts of pattern matching and the development of paradigms and tools for implementing pattern matching, and (3) generalization of these concepts to high-level list scanning and pattern-matching facilities.

University of California-Irvine; Peter A. Freeman and James M. Neighbors; *Software Construction Using Components*; (MCS-8103718 A01); $52,002; 12 mos. (Joint support with the Air Force Office of Scientific Research-Total Grant $104,002).

This research involves the effective use of software components. Previous research has resulted in a running prototype system (Draco) which permits the rapid production (with minimum human interaction) of moderate sized programs (1000 lines of executable code) from preexisting software components. Draco is based on the concept of domains that model sets of objects and operations and refinements to reduce expressions in a domain into executable code. The Draco technology employs source-to-source transformations (in each domain) to provide effective optimization of the code. Executable code is produced by refinements into lower-level domains. The overall objective of this project is to push the Draco technology as far as possible to determine its strong and weak points. The specific objective is a demonstration of Draco's capabilities by building three different applications systems of approximately 10,000 lines of code each in a total time of 6 weeks.

University of Southern California; Robert M. Balzer and David Wile; *Supervisory Control of Transformational Implementation Systems*; (MCS-7918792 A02); $120,705; 12 mos. (Joint support with the Software Systems Science Program-Total Grant $241,410).

This project is aimed at the long-term development of Transformational Implementation Systems. The work falls into two categories, systems building and fundamental research. The systems building activity provides essential support as a means of building an experience base for developing the insights and perceptions which guide the research and as an experimental vehicle for testing ideas and hypotheses.

The ultimate system is presently seen as having five sets of facilities:

1. facilities to impose a structure on transformation selection and application, involving planning subsystems, documentation subsystems and maintenance subsystems.
2. facilities to prove applicability criteria of properties of transformations. Transformations may be applied before some properties are proved applicable necessitating subsequent proof of such properties by inference or symbolic execution or via a general purpose theorem prover or a special purpose property prover.
3. facilities to do automatic program simplification and to provide automatic application of low level transformations that seek canonical forms.
4. facilities for combining individual transformations into layer coordinated packages.
5. facilities to generate new transformations for the catalog on the basis of interactive user editing of the state of the program being generated.

University of Colorado-Boulder; William M. Waite; *Code Generation Tools and Techniques*; (MCS-8108063 A01); $58,960; 12 mos.

The goal of the project is to continue the implementation and evaluation of an integrated set of code generator construction tools. The primary emphasis will be upon reduction to practice: Demonstration that certain techniques can be applied routinely by compiler writers to produce viable code generators at acceptable cost. Since automatic code generator construction is feasible at this time, a skilled human must still make appropriate tradeoffs in describing the relationships between source and target concepts. The intent of this effort is to aid in identifying the decisions that must be made and to automate many of the routine tasks that must be subsequently carried out.

Brandeis University; Jacques Cohen; *Software Tools for the Analysis of Programs*; (MCS-7905522 A01); $79,811; 24 mos.

This project involves the study of algorithms and the developing of software which will enable computer users to evaluate and to improve the efficiency of their programs. The following areas will be investigated: (1) studying specific algorithms, (2) extending the analysis to the case of parallel and real-time programs, (3) determining the probabilities with which conditionals are evaluated to true or false, and (4) using program analysis as a guide in program optimization.

Massachusetts Institute of Technology; Gerald J. Sussman, Charles Rich, and Richard C. Waters; *Abstraction, Inspection and Debugging in Programming*; (MCS-8117633); $62,185; 12 mos. (Joint support with the Intelligent Systems Program-Total Grant-$123,832).

Software Engineering has much to learn from other mature engineering disciplines because the problem solving behavior of engineers in different disciplines has many similarities. Three key ideas in current artificial intelligence theories of engineering problem solving are: (l) Abstraction-using a simplified view of the problem to guide the problem solving process. An example of using abstraction in programming is to first implement the desired behavior of a program on typical data before worrying about exception handling. (2) Inspection-problem solving by recognizing the form ("plan") of a solution. In programming, a plan may be a particular control strategy with unspecified primitive actions or an abstract data structure with an unspecified implementation. (3) Debugging-incremental modification of an almost satisfactory solution to a more satisfactory one. In programming, this evolution is triggered as often by a change in the problem specification as by an error in the initial solution. These three techniques are typically used together in a paradigm called AID (for Abstracting, Inspection, and Debugging). First an abstract model of the problem is constructed in which some important details are intentionally omitted. In this simplified view inspection methods are more likely to succeed, yielding the initial form of the solution. Further details of the problem are then added one at a time with corresponding incremental modifications to the solution. This project will investigate this model of program construction.

Massachusetts Institute of Technology; John V. Guttag (In collaboration with Deepak Kapur and David R. Musser, General Electric Company); *Joint Industry/University Cooperative Project to Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8119846); $18,733; 12 mos. (Joint Support with the Theoretical Computer Science Program and the Software Systems Science Program -Total Grant $56,198).

This joint industry/university cooperative project involves the construction of a rewrite rule laboratory. Rewrite rule systems have come into use in a variety of fields of computer science. They are being used in automated theorem provers, in high level languages, and in software engineering applications. The rewrite rule laboratory allows the computer scientist to develop efficient algorithms for rewrite systems, allows for instrumentation of rewrite systems, allows the comparison of rewrite systems, and allows the development of rewrite systems useful in software engineering, automated theorem proving, and high level language development.

The system is being constructed at the General Electric Laboratories in Schenectady, New York and at the Laboratory for Computer Science at the Massachusetts Institute of Technology. Upon completion the system will be distributed to all interested parties.

Cornell University; Ray Teitelbaum; *Syntax-Directed Programming Environments*; (MCS-8202677); $120,455; 12 mos.

The goal of this research is the design and implementation of highly interactive envirnonments for computer programming that will significantly improve programmer productivity. The scope of the research includes instructional as well as professional programming systems, end-user environments as well as software tools that facilitate the creation of such systems, algorithm design as well as system implementation.

The research includes the design, implementation, and distribution of:

—the Synthesizer Generator, a language-independent constructor of syntax-directed editors able to enforce context-sensitive, as well as context-free, structural constraints;

—the Semantics Processor, a language independent constructor of syntax-directed environments providing execution, source-level diagnostic interpretation and debugging, flow analysis, and program anomaly detection;

—a Transformation Specification System for constructing environments providing collections of program transformations for program refinement, optimization, modification, and maintenance.

Cornell University; Robert L. Constable and Alan J. Demers; *On Logics for Program Development*; (MCS-8003349 A01); $82,981; 12 mos. (Joint support with the Theoretical Computer Science Program & Software Systems Science Program-Total Grant $224,981).

This research involves the judicious combination of the strong points of program development methodology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the refinement logic concept. Comparisons with other systems will also be conducted.

General Electric Company; Deepak Kapur and David R. Musser (In collaboration with John V. Guttag, Massachusetts Institute of Technology); *Joint Industry/University Cooperative Project To Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8211621); $11,703; 12 mos. (Joint support with the Theoretical Computer Science and Software Engineering Programs-Total Grant $35,110).

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Ohio State University; Jayashree Ramanathan; *Customizable Workstation Environment* (*Computer Research*); (MCS-8202873); $64,000; 24 mos.

A way to reduce software development and maintenance costs is to provide more effective system support for the programmer. Such system support must be human-engineered to provide programmers with a friendly environment which optimizes the programming effort needed to create reliable programs. The needs of a group of programmers evolve as programmers accumulate experience. Existing environments are not engineered to evolve with the programmers' unique and changing needs. One technique for human-engineering an environment is to design it to be 'extremely customizable'. Such environments can continually evolve to always ensure optimum support for the programming process. This project formulates a new approach for designing and implementing an extremely customizable environment. This approach will be used to implement a (prototype) customizable environment and determine the extent to which the environment functions can be customized in a useful way.

University of Utah; Martin L. Griss; *Implementation Strategies for Portable LISP Based Systems* (*Computer Research*); (MCS-8204247); $112,524; 12 mos.

This project involves continued research in the area of portable LISP-based symbol manipulation systems, computer algebra programs, and personal programming environments. A personal algebra programming environment based on the popular REDUCE program will be developed. Interpreters, algebra systems, LISP-based graphics systems, and related portable system development software will be implemented on various machines. The work includes experimental studies of portable implementation languages, storage management and special evaluation techniques based on hashing and pattern matching. The original grant has led to the development of a new Portable Standard LISP system, PSL, and an efficient LISP-based systems language, SYSLISP, in which PSL and other similar systems may be rapidly written. PSL is now operational on a DEC-20, and will be implemented on a VAX and Apollo 68000-based computer. PSL will be exploited to implement portable experimental computer aided design (CAD) systems for three-dimensional shape and integrated circuits design, and to provide a significant computer algebra component to an experimental CAI system.

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Software Systems Science

Programming Languages: Design, Semantics, Implementation

Stanford University; Terry Winograd; ***Development of a Language for Process Description***; (MCS-8104883); $113,812; 24 mos.

The goal of this project is to develop a language for the description of processes. This language will be like a programming language in that it makes it possible to specify precisely and unambiguously what a system does. It will be unlike programming languages in that it is based on a description of the behavior of the system, rather than a set of instructions to be followed by a machine that will exhibit the behavior. Preliminary versions of a related language already exist and have been used for specifying algorithms for manipulating syntactic structures.

This research will continue the development of the language, focusing on providing a coherent formal semantics for it and on applying it to a series of problems. It will also include the development of an environment for creating and manipulating descriptions in the language and the exploration of its potential to serve as a basis for program verification.

University of California-Berkeley; Susan L. Graham; ***Programming Language Implementation***; (MCS-8005144 A02); $65,850; 12 mos.

The project will comprise both a continuation of ongoing research and an initiation of new investigations pertaining to interactive programming environments. The study of techniques for producing portable compilers; in particular, the development of table-driven methods for the synthetic (i.e., code-generation) phase of compilation will be continued. The table-driven algorithm will be embedded in a complete compiler, both in order to test the feasibility of the technique as a practical tool and to compare it with other designs for retargetable compilers. The LR error recovery technique in the Pascal compiler will be compared with the methods recently developed by other researchers. The compiler technology that has been developed will also be extended to the design of other programming tools, such as editors, debuggers, and program transformation systems. The goal is to facilitate the production of source-language-knowledgeable tools which take their language knowledge from a data base that can be changed readily, thereby "porting" the tool to another source language while maintaining a familar user interface. Finally, some of the particular problems that arise in the implementation of the recently announced programming language ADA will be investigated.

University of Southern California; Edward K. Blum; ***Algebraic Approaches to Programming Concepts and their Semantics***; (MCS-8203666); $91,029; 24 mos.

The general purpose of this research is to study the applicability of algebraic and more general axiomatic methods to the semantics of programming languages and to relate algebraic semantics to operational semantics insofar as this is possible. Since the concept of data types is one of the important aspects of semantics which have been successfully treated by algebraic methods, this will be one of the major areas of investigation. However, the project will focus on implementation of data types using a new algebraic approach to implementation recently initiated by the investigators. This part of the research also has a practical objective: to determine the extent to which algebraic and more general axiomatic methods can be applied to the implementation of the proposed I.E.E.E. floating point type and the proposed Fortran array type. The relation between algebraic and operational semantic specification of these two types will provide a specific context for the comparative study of the algebraic and operational approaches to semantics which will also be done in the more general context of semantics of entire programming languages.

University of Illinois-Urbana; David J. Kuck and Duncan H. Lawrie; ***Software Studies for Parallel Memories, Multiprocessors, and Virtual Memories***; (MCS-8100512 A01); $104,587; 12 mos.

This project is an attempt to bridge a gap between a programmer, organizing his problem sequentially, and computers with modern architectural features that provide the potential advantage of considerable parallelism. Program transformations (optimizations) which take programs written naively in ordinary computer languages and compile them into code taking advantage of given architectural features have been developed. A broader class of architectural features including virtual memory and cache memory is now being considered. Several types of multiprocessors, including various data flow proposals are also to be considered.

A compiler can take advantage of a great deal of information that is available in a source program to map the program onto some computer structure. In particular, much remains to be learned about source language (or precompiler) optimization.

Massachusetts Institute of Technology; John V. Guttag (in collaboration with Deepak Kapur and David R. Musser, General Electric Company); *Joint Industry/University Cooperative Project To Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8119846); $18,732; 12 mos. (Joint support with the Theoretical Computer Science and Software Engineering Programs-Total Grant $56,198).

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General Electric Company; Deepak Kapur and David R. Musser (In collaboration with John V. Guttag, Massachusetts Institute of Technology); *Joint Industry/University Cooperative Project To Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8211621); $11,703; 12 mos. (Joint support with the Theoretical Computer Science and Software Engineering Programs-Total Grant $35,110).

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City University of New York-City College ; Valentin Turchin; *A Supercompiler System Based on the Language REFAL*; (MCS-8007565 A01); $143,243; 24 mos.

This project is a continuation of work aimed at the creation of a programming system based on a supercompiler for REFAL. The purpose of the system is too facilitate the creation of new application-oriented programming languages at low expense, and to perform in the computer a great deal of work on optimization of algorithms, and even on the algorithmization itself. The user of the system will have to formulate only the definition of his problem, its mathematical model, without bothering about the details of algorithmic efficiency and data structure in the real computer. The core of the system is a program called a "supercompiler", which transforms a multi-level semantic definition of a problem in REFAL into an efficient computer program.

New York University; Jacob T. Schwartz; *Optimization of Very High Level Languages*; (MCS-8004349 A02); $50,000; 12 mos.

Building on the success of the present global analysis and data-structure choice algorithms of the SETL system, these techniques will be extended to three related areas:

1. Application of global analysis techniques to improved static methods of program debugging;
2. Development of a partially extensible optimizer, able to handle user-defined object

types in terms of their logical significance rather than their internal structure;

3. Automatic choice of data structures from a broader range of possibilities, including high-efficiency use of lists and B-trees.

Syracuse University; John C. Reynolds; *The Design, Definition, and Implementation of Programming Languages*; (MCS-8017577 A01); $67,533; 12 mos.

Research will be carried out on the design of programming languages and the mathematical definition of their semantics, with emphasis on the design of Algol-based languages and the use of category theory as a definitional tool. Specific topics include: the application of category-sorted algebras to treat implicit conversions and generic operators; the use of a non-functional Cartesian closed category to provide an abstract model of the store; extension and modelling of a language in which interference can be determined syntactically, and development of a variant of specification logic for proving programs in such a language; and models of languages with type binding.

Brown University; Steven P. Reiss; *Automatic Production of Program Development Software*; (MCS-8200670); $76,690; 24 mos.

A two-year program of research will design and develop a set of software tools for the automatic production of program development systems. This work is two-fold. The first part involves expanding and improving the current research in automatic compiler construction. The second part involves extending this research to program development systems. This includes the automatic production of a syntax-directed editor, an incremental compiler, an executor/debugger and other tools from simple specifications of the desired language.

University of Washington; Alan Borning; *Constraint Languages (Computer Research)*; (MCS-8202520); $88,857; 24 mos.

This project will investigate and implement computer languages and systems based on constraints. A constraint specifies a relation that must be maintained. Keeping that relation maintained is left up to the underlying system, rather than being the responsibility of the user. Constraints are thus useful tools for constructing systems for use by people who aren't computer sophisticates. There are two principal aspects to the project. The first is an investigation of issues of constraint representation and constraint satisfaction, building on previous work in the field. The other aspect is the implementation of an interactive, graphical system that allows a user to view and edit constraints and the objects to which they apply in a convenient and easily understood manner.

University of Wisconsin-Madison; Charles N. Fischer; *Advances in the Theory and Design of Diagnostic Compliers and Language-Based Program Development Systems*; (MCS-8202444); $107,236; 24 mos.

Diagnostic compilers are programming language translators that are specially enhanced to aid in the rapid detection and correction of programming errors. Language-based program development systems integrate editing, debugging and diagnostic tools into a single, "user-friendly" package.

This project will investigate topics in the design, implementation and automatic generation of diagnostic compilers and program development systems.

Methods of improving the accuracy and scope of automatic correction algorithms will be studied. These will include utilization of extended context in making correction decisions, the use of new parsing techniques and the inclusion of semantic information in the correction process.

Automatic code generation techniques, based on attributed parsing methods will be studied. These techniques will allow compilers to be retargeted to new computers in an efficient and automatic manner.

Finally, the use of diagnostic techniques in language-specific program editors will be considered. A prototype editor has already been built. Ways of providing fault-tolerance in user interactions will be studied. Questions of efficient implementation and uniform data/program interfaces will also be investigated.

Operating Systems and Concurrency

Stanford University; Susan S. Owicki and David C. Luckham; *Specification Methods for Parallel Programs (Computer Research)*; (MCS-8015336 A01); $79,000; 12 mos.

This project will investigate methods for specifying parallel programs, focusing attention on three important areas:

1. Formulation of requirements: study and precise formulation of properties required of parallel programs in practice,
2. Specification languages: design of high level languages in which the required properties may be stated easily, and
3. Methods of program specification: study of different kinds of specifications and how they constrain the various components of a parallel program; formulation of standards and methods of program documentation.

University of Colorado-Boulder; Paul Harter; *Investigations into the Application of Temporal Logic to Real-Time Programming*; (MCS-8216707); $21,570; 22 mos.

Software reliability is an important issue in computing science today. It is perhaps of greatest concern in the area of real-time programming because of the nature of its areas of application. One of the major approaches to obtaining reliable software has been the application of formal verification techniques to prove correctness. Unfortunately, concurrent programs and in particular real-time programs have not been shown amenable to current proof techniques.

Recent success by some investigators in the application of temporal logic to proving 'liveness properties' in concurrent programming has led to an attempt to apply it to the real-time case as well.

Work to date has led to the development of new proof techniques applicable to real-time programs. In particular 'safety properties' have been proved, i.e. that undesirable things will not happen. This project will investigate the proof techniques required for general 'liveness properties', i.e. that desired things do happen, in a real-time environment and the completeness or adequacy of the resulting proof system as a whole.

State University of New York Stony-Brook; Paul Harter and Arthur Bernstein; *Investigations into the Application of Temporal Logic to Real-Time Programming*; (MCS-8121857); $37,430; 24 mos.

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University of Pittsburgh; John P. Kearns and Mary Lou Soffa; *The Implementation of Concurrency (Computer Research)*; (MCS-8119341); $84,827; 24 mos.

The growing importance of concurrency as a natural programming paradigm, particularly in embedded real-time systems, renders the efficient implementation of concurrency imperative. There currently exists no reasonably rigorous methodology for expressing the demand placed upon an execution vehicle by a program which consists of a number of cooperating tasks. The development of such a methodology would seem to be a necessary prerequisite for the rational design of language implementations which support concurrency.

The methodology mentioned above will be developed as the initial step of an in-depth study of the implementation of concurrency. This study will address performance evaluation techniques for implementations of concurrent control, the design of language primitives which express concurrency in a manner conducive to their efficient implementation, and the determination of the impact that the execution system has on the concurrency implementation.

Carnegie-Mellon University; Edmund M. Clarke; *Design and Verification of Concurrent Systems (Computer Research)*; (MCS-8216706); $32,700; 10 mos.

The rapid development of computer networks and multiprocessor systems has increased the need for methods of constructing reliable concurrent systems. This project is directed at improved understanding in three particularly important areas of concurrent system development:

1. Specification and verification of concurrent systems.Proof rules for liveness properties of concurrent programs are difficult to formulate because such properties lack continuous fixpoint characterizations. It may be possible to construct concurrent programs in which the synchronization skeleton is automatically synthesized from a high-level temporal logic specification.
2. Construction of distributed algorithms.Protocols, such as the distributed termination protocol, that can be superimposed over a distributed program to ensure some particular behaviour will be studied. Also, it may be possible to transform the specification of a sequential program into that of an equivalent distributed program.
3. Fault-tolerant computing.Multiple resources potentially enable a system to continue functioning despite hardware errors. Software to detect errors and to reconfigure the system into a reliable subsystem is required. A current line of research on such reconfiguration strategies will be extended.

Data Bases

Georgia Institute of Technology; Nancy D. Griffeth; *Design of Distributed Database Systems*; (MCS-8200854); $84,632; 24 mos.

The objective of this research project is to build and use an experimental software tool for simulating the behavior of distributed algorithms. In this particular project, the tool will be used to study distributed database algorithms. The project will also contribute to the development of new database algorithms, on the basis of the simulations and to the development of experimental and analytical techniques for studying distributed algorithms in general.

The study and development of distributed algorithms in general and distributed database algorithms in particular is hampered by the lack of experience with distributed systems. Both intuition and current analytical tools are inadequate to characterize their behavior. Another barrier to understanding such algorithms is the complexity of their interaction, due to the lack of synchronization between nodes of a distributed system. As a result, many algorithms may exist for solving a single problem. Without more experience and analysis, their behavior cannot be well understood or compared.

The immediate significance of this research will be to clarify the differences and similarities among various distributed database algorithms. In addition, a design tool for distributed database systems will be available, part of which will be applicable to distributed systems in general. The specific results will also be applicable to systems other than distributed database systems.

State University of New York-Albany; Daniel J. Rosenkrantz; *Analysis of Structures in Database Systems*; (MCS-8203237); $94,216; 24 mos.

This project involves investigating database concurrency controls, processing predicates and queries, and computing in algebraic systems.

A large number of concurrency controls have been suggested, but each has some aspect that appears inefficient or otherwise undesirable. The extent to which undesirable features are intrinsic to the concurrency control problem will be investigated.

Attention will focus on distributed controls, and on the extent to which serializability can be avoided. Tradeoffs and algorithmic issues will be investigated. The SUNY Albany database simulator will be enhanced.

Properties of languages for expressing database queries and predicates will be investigated. Issues considered will be succinctness, expressive power, and the computational complexity of such problems as minimization and testing equivalence. The relationship between relational algebra and other algebraic systems will be explored.

Computing over algebraic systems is of general theoretical interest. The focus of this work will be the complexity of testing formulas or straight-line programs as a function of the algebraic structure which is the interpretation of the variables and algebraic operators.

Programming Methodology

Stanford University; Donald E. Knuth; *Analysis of Algorithms*; (MCS-7723738 A04); $204,439; 12 mos.

The present program of research in the Analysis of Algorithms will be continued. The research is oriented toward an improved quantitative understanding of the fundamental algorithms of computer science, and it comprises five major activities:

1. Development of new, efficient methods for use on computers;
2. Analysis of the performance of important computer techniques;
3. Analysis of the computational complexity of problems;
4. Studies of programming languages; and
5. Combinatorial theory to support the above activities.

Stanford University; Zohar Manna; *A Deductive Approach to Program Synthesis (Computer Research)*; (MCS-7909495 A02); $66,000; 12 mos.

Program synthesis is the systematic derivation of a program from given specifications. This specification constitutes a high-level description of the desired program which expresses the purpose of the program, without indicating the method by which that purpose is to be achieved. A deductive approach to program synthesis will be used for the construction of recursive programs. Such an approach regards program synthesis as a theorem-proving task and relies on a theorem-proving method that combines the features of transformation rules, unification, and mathematical induction within a single framework.

This project will focus on:

1. Development of subsidiary procedures; construct systems of procedures that form together the desired recursive program.
2. Generalization of programs; extend the given specification to represent a more general problem that is, nevertheless, easier to solve.
3. Construction of programs with side effects; construct programs that can change the values of variables and manipulate other data structures.

SRI International; Joseph A. Goguen; *Exceptions and Non-Termination for Abstract Data Types-Partial and Continuous Algebras (Computer Research)*; (MCS-8201380); $48,940; 24 mos. (Joint support with the Theoretical Computer Science Program-Total Grant $97,881).

The goal of this research is to extend present algebraic specification techniques, which have so far been largely applied to the specification of discrete data structures, so as to encompass abstract control structures (e.g., do-while and backtracking), computations which do not necessarily terminate (e.g., operating systems), exception (or error) handling and recovery, and infinitary data structures. The effectiveness of solutions, and in particular the computability and proof theory of infinitary and error data structures, and their relationship with "direct" implementations by rewrite rules, are investigated. Implications of the findings for programming methodology are also studied, and in particular, suitable extensions for the specification language CLEAR and its semantics are developed.

Extending and parameterizing abstract data types give rise to delicate problems of consistency, especially in the context of exceptions and non-termination, which are part of the investigation.

SRI International; Leslie Lamport; *The Specification and Verification of Concurrent Programs*; (MCS-8104459 A01); $98,126; 12 mos.

A general method for the formal specification and verification of concurrent programs will be developed. Two current approaches, temporal logic and our generalization of Hoare's program logic, will be merged into a unifying logic for concurrent programs. This logic will permit reasoning about properties of a program without requiring its implementation to be described in terms of indivisible operations. It will encompass our current work on a fundamental theory of distributed concurrent systems.

The logic will be used as the basis for an hierarchical specification and verification methodology. In developing this methodology, we will formulate temporal logic techniques for specifying the semantics of sophisticated programming language features. The utility of the approach will be demonstrated by its application to several examples, including a hierarchical system of network protocols.

SRI International; Richard J. Waldinger; *The Automatic Synthesis of Computer Programs*; (MCS-8105565); $74,227; 12 mos.

Program synthesis is the automatic derivation of a computer program to meet a given specification. The specification expresses the purpose of the desired program, but does not need to give any indication of the method by which that purpose is to be achieved. The ultimate goal of program synthesis is to automate the programming process. Interim goals include conceptual and mechanical aids for program derivation and improved methods for program verification, program transformation, and the semantic description of programming languages.

A deductive approach to program synthesis has been developed in which, to construct a program is regarded as a problem of finding a proof of a mathematical theorem. This approach has been developed for the synthesis of "applicative" programs—LISP-like programs that return an output value but produce no side effects. The focus of the present research is to extend the deductive approach to the synthesis of nonapplicative programs, which may produce side effects as well as return output values. For this purpose, the deductive system in which proofs are conducted is extended to employ a situational calculus, which allows explicit mention of the states of a computation, so that side effects—changes of state—may be easily described. The specification of the desired program and the description of the constructs of the target programming language can then be expressed in terms of the operators of situational-calculus, and the program can be extracted from a proof of the appropriate situational-calculus theorem. The approach is amenable to machine implementation, and the same system can be applied to the verification and transformation of computer program, as well as to their synthesis.

University of Southern California; Robert M. Balzer and David Wile; *Supervisory Control of Transformational Implementation Systems*; (MCS-7918792 A02); $120,705; 12 mos. (Joint support with the Software Engineering Program-Total Grant $241,410).

This project is aimed at the long-term development of Transformational Implementation Systems. The work falls into two categories, systems building and fundamental research. The systems building activity provides essential support as a means of building an experience base for developing the insights and perceptions which guide the research and as an experimental vehicle for testing ideas and hypotheses.

The ultimate system is presently seen as having five sets of facilities:

1. facilities to impose a structure on transformation selection and application, involving planning subsystems, documentation subsystems and maintenance subsystems.
2. facilities to prove applicability criteria of properties of transformations. Transformations may be applied before some properties are proved applicable necessitating subsequent proof of such properties by inference or symbolic execution or via a general purpose theorem prover or a special purpose property prover.
3. facilities to do automatic program simplification and to provide automatic application of low level transformations that seek canonical forms.
4. facilities for combining individual transformations into layer coordinated packages.
5. facilities to generate new transformations for the catalog on the basis of interactive user editing of the state of the program being generated.

Indiana University-Bloomington; David S. Wise and Daniel P. Friedman; *Applicative Programming for Indeterminate Systems* (*Computer Research*); (MCS-8203978); $129,171; 24 mos.

Indeterminate systems are operating systems, data base systems, distributed systems, and multiprocesser systems that require real-time response to many independent conditions that occur with a relative synchronization not known at the time the system is built. Applicative or functional programming is a style of expressing computer algorithms as mathematical function definitions, which are specifically devoid of time- and side-effects.

Extending applicative programming to deal with the essential properties of timing in systems is important because it is already so promising for efficient use of these same systems for time-independent tasks. Traditional programming styles do not make good use of parallelism available in new architectures because they have been modelled after single processor computers. They have however, been extended to deal with synchronization issues. Applicative languages, which can well use parallelism unknown to the programmer, have not been extended to deal with all of the problems in working with such systems.

The DAISY programming language and DSI system will be developed to a production environment that can cope with issues of indeterminism among input conditions, breadth-first evaluation of condition trees, failures of output devices, and embedded systems. System performance will be refined with respect to program maintenance and automatic introduction of sequentiality to reduce time and space needs.

Dartmouth College; L. Paul Chew; *Efficient Strategies for Finding Normal Forms* (*Computer Research*); (MCS-8204821); $31,658; 24 mos.

Many problems in computer science can be described in terms of replacement rules which tell how to transform representations of entities. The entities might be computer programs or specifications of data types or certain theorems. The normal form of an entity is that representation that additionally has some predefined property (for example, minimum length or using only a limited set of functions). One may not be able to prove whether a normal form of a particular entity exists so that, in general, one cannot find an upper bound for the number of transformations required by some strategy to find a normal form. Nevertheless, strategies for finding normal forms exist, some being more efficient (requiring fewer transformations) than others. The goals of this project are to (1) develop methods to compare the efficiencies of different strategies for finding normal forms, and (2) develop a provably efficient strategy for finding normal forms.

Cornell University; Robert L. Constable; ***The Metamathematics of Programming Logics***; (MCS-8104018 A01); $35,254; 12 mos.

A programming logic is a formal system in which programmers can specify computational problems, develop provably correct algorithms to solve them and then execute these algorithms. An implemented system provides mechanical assistance in all phases of this process. Theoretical work is needed to guide the design, implementation, and use of programming logics. Significant results have been obtained about programming logics. Future investigation will concentrate on the proof theory of an algorithmic theory of types, a theory which appears to be a necessary and perhaps sufficient programming logic.

Cornell University; David J. Gries and Fred B. Schneider; ***Programming Methodology*** (***Computer Research***); (MCS-8103605 A01); $112,404; 12 mos.

This research is concerned with advancing the science of computer programming, with respect to concurrent as well as sequential programs. Techniques for the development of provably correct and easily understood programs will be developed and used. A by-product will be more insight into how better to teach programming.

A major theme of this work is the axiomatic approach and use of weakest precondition predicate transformers in the derivation of programs and in the definition of programming constructs. Extension and application of this methodology to the design and implementation of large programming problems will demonstrate its utility for "programming-in-the-large". Extensions for designing fault-tolerant software as well as techniques for understanding concurrent programs and proving them correct, with emphasis on distributed programs, will be studied.

Both theoretical and practical issues will be explored. It is expected that new algorithms for old problems will be discovered. The discovery of new problems, their solutions, and paradigms for developing distributed programs is also anticipated. Among the initial problems to be attacked are: network routing protocols, decentralized algorithms for resource allocation, and synchronization.

University of Texas-Austin; Frank M. Brown; ***Automatic Analysis of Algorithms***; (MCS-8113510); $90,106; 24 mos.

This project will use an automatic theorem prover which is capable of handling real algebra with recursive functions over arbitrary data objects to study the proofs of theorems concerning the complexity of recursive LISP programs. This investigation is directed toward the verification of programs not only according to their functional specification (that they do what they are supposed to do) but also according to performance specifications (that they do it within a certain period of time or with a certain amount of resources).

Washington State University; David B. Benson; ***Algebraic Reasoning about Computer Program Behaviors***; (MCS-8003433 A01); $97,079; 24 mos.

This project will investigate the denotational semantics of nondeterministic and parallel programming languages as well as nondeterministic and parallel specification techniques. A particular objective is the development of well-founded methods of reasoning about programs and formal specifications which are crisp and easy to understand. Algebraic methods will be applied to the study of programming languages with certain semantic features—various forms of nondeterminism and parallelism. This will indicate that well-founded domains of algebraic reasoning can become useful to programmers and specifiers in the near future.

Distributed Computing

University of Arizona; Gregory R. Andrews; *The Design and Analysis of Distributed Programs*; (MCS-8202869); $152,521; 24 mos. (Joint support with the Software Engineering Program-Total Grant $197,521).

This project is concerned with the design and analysis of integrated distributed systems, which execute on and control a local network of processors.

The focus of the project is on the nature of and relation between communication, concurrency and robustness. The topics being addressed are: the semantics of distributed programming languages, language mechanisms for dealing with failures, programming techniques for achieving robustness, and analytic methods for evaluating distributed algorithms.

One of the goals is to use the technique of pools of servers to construct a working prototype of a network operating system that is implemented in the distributed programming language SR. The ultimate goal is to develop a deeper understanding of the semantics of distributed programming and the tradeoffs between concurrency, communication, and robustness.

Massachusetts Institute of Technology; Barbara H. Liskov; *Issues in Fault-Tolerant Distributed Programs (Computer Research)*; (MCS-8203486); $129,821; 12 mos.

This research is concerned with problems that arise in fault-tolerant distributed programs. While interests within this area are very broad, ranging from distributed algorithms to program structure to program specification and verification, the project is focussed on defining a programming language and system, called Argus, that supports the construction and execution of fault-tolerant distributed programs. Argus will be used to study the other problems, both at the level of user programs, and at the level of system support.

The main recent achievement has been the design of Argus. This language is designed to satisfy a number of requirements that have been identified by studying application programs. Issues that arise in the implementation of Argus have been examined and some algorithms in this area have been developed.

The project will continue work on the language design and will do a realistic, distributed implementation of Argus. Theoretical work to enhance the understanding of new concepts that are arising will also be carried out.

University of Rochester; Carla S. Ellis; *Language Constructs and Support Systems for Distributed Computing*; (MCS-8203306); $93,677; 24 mos.

The ideal computing environment for many applications is a set of machines with different capabilities so that each subproblem can be solved using appropriate resources and a communications network connecting them. The technology exists to build such a heterogeneous network, but programming systems that make it easy for users to design and execute distributed programs are lacking. The purpose of this project is to develop programming language constructs and management strategies that support reliability and an appropriate degree of network transparency.

The model underlying this system design work is based on a notion called an activity that serves as a structuring tool for objects. The properties that characterize the relationships among activities, their subactivities, and objects will be defined. A support system that provides registration, synchronization, and fault tolerance based on activities will be designed and implemented. Sufficiently high-level language constructs that allow access to the services provided by the support system as well as constructs which aid in organizing the activity-related state internal to an object will be studied. Finally, the compatability of these constructs with contemporary computing environments and the adequacy for a range of potentially distributed applications will be assessed.

University of Wisconsin-Madison; Robert P. Cook; *Experiments in Distributed Computing*; (MCS-8003341 A01); $66,280; 24 mos.

The experiments which will be performed as part of this project are designed to provide guidelines for the construction of a computer network which is a high-level language machine. The software tools constructed as part of the StarMod project will be extended. Subprojects include simulation facilities, high-level language machine design, distributed programming language design, a software-partitionable multicomputer, a distributed file system, and a dynamic program maintenance facility.

Verification

Cornell University; Robert L. Constable and Alan J. Demers; *On Logics for Program Development*; (MCS-8003349 A01); $77,500; 12 mos. (Joint support with the Software Engineering Program and Theoretical Computer Science Program-Total Grant $224,981).

This research involves the judicious combination of the strong points of program development methodology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the refinement logic concept. Comparisons with other systems will also be conducted.

University of Texas-Austin; Robert S. Boyer and J. Strother Moore; *Mechanizing the Mathematics of Computer Program Analysis*; (MCS-8202943); $98,196; 12 mos.

The aim of this project is to make practical the use of computers to prove facts about computer programs. A practical, mechanical method for certifying computer programs would substantially increase their reliability and decrease their cost. A logic convenient for specifying properties of computations has been developed and a computer system using that logic has been applied to prove facts about FORTRAN programs, functional programs, machine code programs, and real time control programs. The system has even been used to prove the soundness of some additions to itself. The development of the logic and construction of the system was supported in part by NSF Grant MCS-7904081. To enhance the logic of this system, the class of acceptable induction principles will be extended to permit the expression of schematic concepts with bound variables. Several improvements of the system's theorem-proving power will be made, including: the use of more decision procedures, the exploitation of facts about congruence relations, more effective control of forward and backward chaining, and the use of our theorem-prover by our compiler. The interface between the system and the user will also be improved.

Special Projects

Data Handling, Data Manipulation, and Database Research

University of California-Berkeley; Alan J. Smith; *Automatic File and I/O System Design and Optimization*; (MCS-8202591); $65,000; 12 mos.

This research will include four related topics:

1. Development and evaluation of algorithms for the migration of files between secondary and tertiary storage (medium and long term migration);
2. Development and evaluation of designs for cache disks and for the algorithms to manage them;
3. Development and evaluation of algorithms for the management of distributed file systems; and
4. Analysis of user behavior and workloads, primarily as they relate to file migration in a memory hierarchy and across a distributed file system.

The outcome of this research will be a body of empirically validated algorithms and designs, based on theoretical and experimental studies, which will significantly improve the operation of computer systems.

The methodology of this research can be characterized as experimental computer science. Traces of real file system operation (most of which already exist and have been reduced to usable form) will be analyzed, characterized, and used as the basis for algorithm development and device design. The results of this research will be implemented on one or more DEC VAX 11/780. Evaluation of the results of this research will be done both by implementation and by trace driven simulation. We expect that the results of this research will be applicable to a very wide range of computer installations from large minicomputers to massive computer centers. The wide variety of traces available will permit tests of the range of applicability of the results.

Harvard University; Nathan Goodman; *Tree Cyclic Schemas in Database Query Processing*; (MCS-8201429); $66,700; 24 mos.

Relational databases have abstract representations called relational database schemas. These schemas can be partitioned into cyclic or tree schemas. The partition has important consequences in two areas of database theory: query processing and dependency theory. The investigator will concentrate on query processing issues related to the dichotomy between these approaches with particular emphasis on: database state reductions with functional dependencies, minimization of genuine joins for query solution, and development of a framework for query processing.

Vanderbilt University; Patrick C. Fischer; *Query Formulation and Processing*; (MCS-8115106); $72,237; 24 mos.

Research will continue on query processing, but future emphasis will be placed on the problem of query formulation. Two main approaches will be investigated. One is the design of a computer assisted query language which facilitates system-user understanding and is able to deal with users with different levels of knowledge of the system. The other involves extensions of the relational data model to increase storage efficiency and to model more accurately the user's enterprise. Common to the two approaches is the need to view the conceptual model as a set of distinct tables rather than as projections of a single relation instance. We seek ways to describe the semantic aspects of this conceptual model which are consistent with but more powerful than today's knowledge of dependency theory.

University of Wisconsin-Madison; Randy H. Katz; *A Data Management System for VLSI Design Data*; (MCS-8201860); $67,798; 24 mos.

This research will emphasize a database management system approach to managing the information about Very Large Scale Integrated (VLSI) circuit designs. The database component, based on relational database techniques, will provide an interface to stored data. A design management system, that supports the hierarchical construction of a VLSI circuit design from primitive cells, will be built on top of the database component and will be responsible for organizing data about alternative design representations and versions. Finally, programs that provide a tailored interface to design

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data, based on its semantic content, can be built on top of the design data manager. The system should simplify the rapid construction of new tools for VLSI design by relieving the tools designer of the burden of managing the design data.

The important research questions to be investigated include using the design hierarchy to enhance parallel design activity, propagation of changes through the design hierarchy and to other design representations, and support for alternative designs that can later be merged into a single coherent design.

Privacy and Security

Stanford University; Martin E. Hellman; *Data Security*; (ECS-7916161 A03); $14,000; 12 mos. (Joint support with the Electrical & Optical Communications Program-Total Grant $58,083).

This research program is concerned with increasing the understanding of the use of cryptography in data security. Public key cryptosystems and their relationship to digital signatures are being studied along with cryptographic systems with a high level of mathematical structure. Efforts are being devoted to the certification process by which a system is tested for weaknesses prior to being designated as secure. The study is directed to general methods, such as time-memory tradeoffs, and to specific cryptographic systems, such as the Federal Data Encryption Standard.

University of California-Berkeley; Manuel Blum; *Transaction Protection Protocols* (*Computer Research*); (MCS-8204506); $74,450; 12 mos.

The objective of this research is to develop, study and experiment with protocols for protecting electronic business transactions. A number of such protocols have already been developed for sending certified mail, signing contracts, and exchanging secrets. A problem in each case is to achieve the equivalent of PARALLELISM through SEQUENTIAL exchange of messages. Signing contracts, for example, normally requires that the two parties to the contract be present at the same place and at the same time for signing. Signing contracts by telephone is difficult, even with computers, since whoever signs first obilgates him/herself first. It is the task of the protocol to achieve the EQUIVALENT of simultaneous signing. This is possible using techniques of number theory and complexity theory that have been developed recently for work on public-key cryptography and signature schemes. The investigators intend to develop protocols for various problems such as these and to further improve those already available in hopes of making them practical. With a few notable exceptions, the published literature does not give proofs of correctness and security, though these are starting to be developed. The investigators expect to contribute to the development of such proofs.

University of Wisconsin-Milwaukee; George I. Davida; *Data Security*; (MCS-8112345 A01); $45,629; 12 mos.

This is a continuation of work on data protection. Emphasis will be on the use of cryptosystems in the design of secure operating systems and secure databases. Distributed computer architectures along with encryption will be investigated to determine the level of security that can be achieved. In databases, an algebra for encrypted relational databases will be investigated.

The Societal Impact of Computing

University of California-Irvine; James N. Danziger and Kenneth L. Kraemer; *A Contingency Analysis of Computer Impacts in Public Organizations*; (MCS-7905521 A02); $71,639; 12 mos.

The success or failure of computer-based systems is commonly held to be related to:

1. The individual attributes of the users;
2. The nature of the technology;
3. The character of the interactions between the information services department and the information users in other departments;
4. The organization's environment, including the political framework; and
5. The size of the community.

This project will assess these factors empirically using contingency theory as the conceptual framework to structure the analysis. It will treat selected aspects of the organization's environment (size, political framework) as forces which influence its structure (organization structure, EDP structure) and also its performance (utilization, productivity, quality of work, problems). It will also examine the user-technology interface (traits of user, nature of the technology, character of user-provider interactions) as an intervening variable between environment and structure on the one hand and performance on the other. The general hypothesis is that environment specifies the strategies which are most appropriate for information systems success. Moreover, the appropriate strategies might vary depending upon the kind of performance criteria examined.

The data for the analyses have been collected from 2176 municipal personnel ranging from top managers and department heads to clerical workers. In explaining between government variation in performance, analyses will be conducted primarily at the city level, and also at the department and role level.

The research results will be disseminated to practitioners as well as to academics in computer science, public administration/political science, and management information systems.

University of California-Irvine; Rob Kling; *Social Dynamics of Computer Use in Complex Organizatons*; (MCS-8117719 & A01); $110,145; 12 mos.

This study investigates three compelling questions that face social analysts of computing:

1. How does the social organization of computing development and delivery influence the kind and quality of computing services available to users;
2. Which theoretical perspectives provide the most explanatory power for analyzing computing developments;
3. How is the interplay between complex information systems and complex social settings best understood.

This project will help answer these questions through a set of theoretical and empirical studies which examine the development and use of a specific type of complex computerized information system-material requirements planning (MRP).

Social analysts of computing often rely upon one of four theoretical perspectives in conceptualizing the social and organizational environment of computing: formal-rational, structural, interactionist, and organizational politics. Each of these perspectives casts a different analytical light on the character of the local computing package. This project will examine the relative explanatory power of these four perspectives in analyzing the development and use of MRP systems.

Four organizations will be studied in depth. They vary considerably in the organizational complexity of their computing arrangements and in the technical complexity of the computing development and use which vary with these complexities.

University of California-Irvine; Kenneth L. Kraemer; *Longitudinal Study of Computer Technology and Impacts in Cities*; (MCS-8115547); $120,000; 24 mos. (Joint support with the Division of Information Science and Technology-Total Grant $185,572).

This research will undertake a longitudinal evaluation of computing in organizations in order to:

1. Empirically determine whether computing use and policies for computing management in organizations evolve along predicted "stage theory" dimensions, and if so, whether the stages described in these theories correspond to the stages discovered in the research,
2. Investigate the "performance dynamics" of computing in organizations as the basis for assessing whether specific policies devised to achieve the benefits and alleviate problems with computing in fact do so, and if not why, and
3. Empirically describe the diffusion of computing innovations in organizations as a template against which future computing growth in organizations can be assessed.

The research focuses on U.S. cities as its "laboratory" for data collection and analysis. It will replicate key aspects of a nation-wide study conducted in 1976, which focused on the relationship between environment, policy and impacts from computing. The outcomes of this research will have substantive policy utility for computing-using organizations generally, for policymaking about the diffusion of computing innovations by federal and state government agencies and the computer industry. The research results should apply to problems in computing system and applications design as well as to information management and organization.

New Jersey Institute of Technology; Starr R. Hiltz; *Determinants of Acceptance of Computer-Mediated Communication Systems*; (MCS-8121865); $80,146; 12 mos.

Building on the results of previous research, the project will:

1. Expand knowledge of the determinants of acceptance which appear to be very important, but about which relatively little is known, including the formation of pre-use attitudes toward computer-mediated communication systems, and the interplay of personality and attitudinal factors.
2. Build a multi-variate model of the determinants of acceptance.
3. Determine, through experimental interventions, the most fruitful combinations of training, orientation, and facilitation to employ for new users of various types in order to maximize acceptance rates.

Modelling and Simulation

Washington University; Mark Franklin; *Continuous Systems Simulation on Multiprocessor Systems*; (MCS-7820731 A03); $76,829; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $116,829).

The principal goal of this project is to increase significantly the solution speed and reduce the costs associated with continous system simulation on computers. The principal vehicle for achieving this goal is the exploitation of multiple processor computer architecture, in particular architecture based on Very Large Scale Integration (VLSI) technology.

The research will be conducted in three main areas:

1. Algorithms, parallel integration methods and higher order numerical problems associated with simulation.
2. Systems architecture, quantifying hardware and software design parameters and system performance metrics.
3. Systems building and research tools development, development of a systems workbench on which new ideas of structure and algorithms can be tried.

Networking, Computer Communications, and Distributed Computing

Massachusetts Institute of Technology; Robert Gallager; *The Dynamics of Data Network Research*; (ECS-7919880 A02); $32,000; 12 mos. (Joint support with the Electrical & Optical Communications Program-Total Grant $120,000).

The objectives of this research are:

1. To develop new models and conceptual approaches for studying the multi-faceted problems of the distributed control of data communication networks,
2. To develop and apply new algorithmic and analytical techniques for solving the problems formulated above,
3. To synthesize these solutions into a better understanding of the underlying tradeoffs that exist in the engineering of efficient, reliable networks, and
4. To use data networks as an example to contribute to a better understanding of the common problems that arise in controlling large scale distributed systems.

The research focuses on the nature of, and the encoding of, the inter-nodal control information (i.e., the protocols) used to accomplish transfers of data in the network. Distributed algorithms for routing and flow control, and the systematic development of building blocks for such distributed algorithms are being considered.

Other Projects, Symposia, Colloquia, and Studies

Stanford University; Gene H. Golub; *Research Workshop in Numerical Methods, Venezuela, June 14-18, 1982*; (INT-8117980); $2,500; 06 mos. (Joint support with the Division of International Programs-Total Grant $12,900).

This award supports the participation by ten U.S. mathematicians in a research oriented workshop in the area of numerical methods. The workshop will be held in Venezuela and it has been organized jointly by Gene Golub of Stanford University and M. Lentini of the Simon Bolivar University. Approximately equal numbers of U.S. and Venezuelan mathematicians will participate, as well as a small number of invited experts from other Latin American countries and from Europe.

The thematic emphasis of the workshop is on the interplay between numerical methods and modern applied mathematics. Particular topics will include differential equations, optimization and sparse matrix problems, all areas of active research currently in the U.S. and Venezuela.

This bilateral workshop is jointly approved and funded by the National Science Foundation and Venezuelan Council for Scientific and Technological Research, under the U.S.-Venezuela Agreement for S&T Cooperation.

National Academy of Sciences; Fred Frishman; *Panel on Evaluation of Statistical Software*; (MCS-8204241); $9,390; 09 mos. (Joint support with Special Projects Program-Mathematical Science Section-Total Grant $18,780).

A panel of users, educators, and specialists in mathematical statistics and computer science will be chosen to perform a feasibility study to determine the extent of the need to evaluate the quality (adequacy, reliability, and accuracy) of existing and subsequently developed statistical software, its impact on various user communities, and on statistical education and research. Further, and as appropriate, the Panel will delineate the extent of the software problem and specify or plan to study and/or solve the problem.

University of Minnesota; George R. Sell and Hans F. Weinberger; *Conference on Computer Architecture and Computational Mathematics, Minneapolis, Minnesota, June 2-4, 1982* (*Mathematical Sciences*); (MCS-8207149); $6,000; 06 mos. (Joint support with Special Projects Program-Mathematical Science Section-Total Grant $11,696).

A conference on computer architecture and computational mathematics will be held in Minneapolis, Minnesota, on June 2-4, 1982.

The conference will be devoted to the areas of computer architecture and computational mathematics. These two areas of computer science and mathematics are very closely interrelated. Computer architecture imposes physical limits on what is available for mathematical computation, whereas the needs of scientific computation can give direction to new developments in computer architecture. This conference will provide an opportunity for leading scientists from these two areas to engage in meaningful exchange.

Princeton University; Bruce W. Arden and David P. Dobkin; *VLSI Design and Testing Environment* (*Computer Research*); (MCS-8121851); $149,150; 24 mos. (Joint support with the Computer Systems Design Program-Total Grant $249, 150).

This award will aid in the establishment of an experimental facility to support a program of research in computer-aided, very-large scale integrated (VLSI) circuit design, development and testing. The facility will include powerful design workstations interconnected by a high bandwidth communications network.

The goal of the Princeton VLSI Project is to develop a total environment for the creation of VLSI circuits from design through testing to fabrication. Individual projects will be coordinated to insure that they contribute to an integrated environment. These projects include research in tools, techniques, and algorithms for circuit specification, circuit layout, and circuit verification.

The approach taken in the VLSI Project is based on a view that VLSI development is essentially a programming process. Research in circuit specification will build on the Census language and the census model developed by the investigators. The programming language, ALI, which is a Pascal extension will be the basis for further research into circuit layout techniques and aids. The research in circuit verification will emphasize validation of the translation process from high-level specificaton to actual circuit.

Duke University; Alan W. Biermann; *Voice Interactive Computer Systems*; (MCS-8113491); $54,041; 12 mos. (Joint support with the Division of Information Science and Technology-Total Grant $108,041).

The investigators will study the dynamics of human-machine voice interactive problem solving with the goal of constructing fast and efficient voice interactive computer systems. The approach to establishing human-machine voice communication will include discovering both how to train potential users to limit their speech to a reasonable subset of English and how to stretch the technologies of voice and language processing to cover that subset. Studies will be made of human speech behavior in problem solving situations and a voice interactive computer system will be constructed to process it.

The proposed voice interactive system will allow the user to display data on a computer terminal and manipulate it using voice commands and touch sensitive inputs to the screen. Each command will result in immediate action visible on the screen allowing the user to confirm that a proper response has occurred. If an error is observed, the user may request a "back-up" and then rephrase the command in more careful terms. System prompts and error messages will be returned by synthesized voice and the total system design will be styled for fast, convenient interactive behavior. This system will be an extension of the NLC natural language programming system which has been built and tested over the last several years.

This project is collaborative research with Dr. Robert Rodman of North Carolina State University.

North Carolina State University; Robert D. Rodman; *Voice Interactive Computer Systems*; (MCS-8114206); $16,743; 12 mos. (Joint support with the Division of Information Science and Technology-Total Grant $33,243).

The investigators will study the dynamics of human-machine voice interactive problem solving with the goal of constructing fast and efficient voice interactive computer systems. The approach to establishing human-machine voice communication will include discovering both how to train potential users to limit their speech to a reasonable subset of English and how to stretch the technologies of voice and language processing to cover that subset. Studies will be made of human speech behavior in problem solving situations and a voice interactive computer system will be constructed to process it.

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This project is collaborative research with Dr. Alan Biermann of Duke University.

University of Pennsylvania; Peter Buneman; ***Workshop on Database Interface Methods to be held October 25-26, 1982 in Philadelphia, Pennyslvania***; (MCS-8120985); $20,248; 12 mos.

One of the most severe bottlenecks in many computer applications is in communication with databases. This confronts the "end user", who finds his method of querying the database too obtuse, not powerful enough, too complicated, or not helpful; and it confronts the applications programmer who usually finds the tools for communication with the database greatly inferior to the tools generally available in modern high-level programming languages. Considerable effort is now being made to improve this situation, and not only by those who study databases and programming languages, but notably by the implementors of systems that provide helpful access to the database through natural language. However, there are many outstanding problems in this field, and there is considerable disagreement on what is needed.

The workshop will bring together people whose research involves the construction of database interfaces to produce a set of working papers that describe this research and the problems encountered by users of such interfaces.

Theoretical Computer Science

Concrete Complexity and Analysis of Algorithms

Stanford University; Jeffrey D. Ullman; *Theoretical Investigations into Very Large Scale Integrated Circuit Technology* (*Computer Research*); (MCS-8203405); $53,671; 12 mos.

Concepts from theoretical computer science are applied to problems of integrated circuit technology. There are a variety of tools that the designer of VLSI circuits requires. The complexity of the algorithms used in such tools (e.g., simulators, design rule checkers) is investigated in the hope of developing superior algorithms or at least understanding the tradeoffs between speed and generality of input that must be made. Another area ripe for the design of tools is automatic routing. While the general problem is intractable, simple cases have been solved recently, and these solutions influence the way man and machine should interact to design circuits. There are also many algorithm design questions that are influenced by VLSI technology. For example, the design of systolic algorithms becomes very important, as does the study of parallelism in general. Complexity takes on new meaning, with issues such as pipelining, off-chip communication, and replication of inputs joining time and space as interacting criteria of goodness for algorithms. Hence, techniques for the development of good VLSI-oriented algorithms, with consideration given to the fundamental limits implied by the new models, are investigated.

University of California-Berkeley; Richard M. Karp; *Combinatorial Algorithms and Computational Complexity* (*Computer Research*); (MCS-8105217 A01); $88,612; 12 mos.

This research focuses on six interrelated themes: probabilistic analysis of algorithms, randomized algorithms, algorithms for determining the reliability of a complex system, algorithms for the enumeration of graph-theoretic objects, machine-based complexity theory and concrete complexity theory. Tools from computational complexity, operations research, and combinatorics are used to discover upper and lower time and space bounds for problems in these areas.

University of California-San Diego; Michael L. Fredman; *The Complexity of Data Structures and Related Topics* (*Computer Research*); (MCS-8204031); $56,686; 24 mos.

This project concerns representation, retrieval, and manipulation of information, with emphasis on computational complexity. One goal is to develop techniques for designing efficient data structures and manipulation algorithms for various classes of on-line computational problems. A second, related, goal is to develop techniques for deriving inherent lower bounds on complexity, as well as inherent complexity trade-offs for various classes of on-line problems. Both of these goals entail the development of models of computation general enough so that results with respect to these models are interesting, while being sufficiently restrictive to permit a tractable analysis. Finally, possible relationships between various models of computation are explored.

University of California-San Diego; Te C. Hu; *Theory and Computation of Discrete Optimization* (*Computer Research*); (MCS-8003362 A03); $30,035; 12 mos.

The class of network flow problems is a subclass of linear programming problems, but special algorithms are needed for the network flow problems. Now, there is a subclass C of dynamic programming problems which also needs special algorithms. The dynamic programming needs $0(n^3)$ time to solve the class C while the investigator has developed algorithms requiring 0(nlogn) or $0(n^2)$ time to solve many problems in the class C including alphabetic codes, N-order statistics, matrix computation, etc. The investigator will characterize the class C and develop new algorithms and data structures to solve the problems in C.

University of Southern California; Leonard Adleman; *Computation Complexity and its Relationship to Number Theory* (*Computer Research*); (MCS-8022533 A02); $42,982; 12 mos.

Research is planned in three areas: Computational complexity, cryptography, and VLSI.

1. Computational Complexity. Several aspects of computational complexity will be investigated with particular emphasis on its relationship to number theory. Much will center on the P=NP problem.
2. Cryptography. Public security and privacy.
3. VLSI. The VLSI related problems are; layout, design aids, design paradigms, and complexity.

Yale University; Michael J. Fischer; *Advanced Computing Structures* (*Computer Research*); (MCS-8116678 A01); $72,892; 12 mos.

The investigator will develop theory in several practical areas of computing. Goals are to find good abstract models, improved and inherent limitations. Particular topics to be studied include communicating processes, very large scale integrated circuits (VLSI), text editing, and time and space requirements of natural problems.

Yale University; David Lichtenstein; *Graph Connectivity and Applications* (*Computer Research*); (MCS-8204246); $60,397; 24 mos.

Two topics are studied. The first is an investigation of theorems characterizing decompositions of graphs into highly connected components. The second is a search for applications of decomposition theorems to outstanding problems in computational graph theory, namely, the k-paths problem, the subgraph homeomorphism problem, and a network reliability problem.

University of Georgia; Samuel S. Wagstaff; *Computations in Number Theory*; (MCS-8202356); $7,489; 12 mos.(Joint support with the Algebra and Number Theory Program-Total Grant $14,977).

The zeros of L-functions for certain Dirichlet characters are studied. Formulas for the efficient evaluation of these functions are developed and used to prove theorems about primes in certain arithmetic progressions. The analog for L-functions of the Riemann-Siegel asymptotic formula is used to evaluate the L-functions on the line $\mathrm{Re}\, s = 1/2$. The calculation is the first large-scale test of the Extended Riemann Hypothesis, which is a conjecture with important consequences.

Continued fraction factorization of large numbers is also investigated. This work is a step toward determining the computational complexity of factoring large integers. Great interest has been focused on this problem recently because of its connection with public key cryptosystems.

University of Illinois-Urbana; Chung L. Liu; *Combinatorial Algorithms* (*Computer Research*); (MCS-8107647 A01); $41,314; 12 mos.

The average case and worst case time complexities of a variety of combinatorial algorithms are investigated with particular attention paid to heuristics. The specific algorithms studied include scheduling algorithms, sensitivity analysis of heuristic algorithms, error analysis in dynamic programming problems, graph algorithms, combinatorial properties of trees and data movement algorithms in magnetic bubble memories.

University of Illinois-Urbana; Franco P. Preparata; *Parallel Computation and the Impact of VLSI* (*Computer Research*); (MCS-8105552 A01); $41,927; 12 mos.

The principal topic of investigation is parallel computation. Two directions are explored:

1. Parallel computations
2. VLSI circuit design algorithms.

Parallel computation provides a fundamental answer to the need of increasing computer processing time. Technological advances have made it possible to realize parallel computing systems. Topics studied include the development of realistic computation models, the study of architectures realizable in the chosen models, and the analysis and design of algorithms executed on the chosen architectures.

VLSI circuit design algorithms are necessary in order for the full potential of VLSI to be realized. Effectiveness is realized through the development of layout algorithms which minimize chip area while complying with constraints imposed by VLSI circuit process technology.

Event based models of parallel computation are studied. Non-determinism in these models is expressed as a second order notion and the models are used to provide semantics for programming specification languages such as CSP.

University of Illinois-Urbana; Edward M. Reingold; *Analysis of Combinatorial Algorithms* (*Computer Research*); (MCS-8117364); $83,442; 24 mos.

Combinatorial algorithms are algorithms that count, manipulate, or match collections of objects. They comprise much of the core of computer science. In this research project four types of combinatorial algorithms are studied: matching algorithms for graphs, the construction and maintenance of optimal binary search trees, geometric covering algorithms, and layout algorithms for trees. The focus of this work is on developing heuristics to obtain good average time algorithm performance.

Northwestern University; Der-Tsai Lee; *Concrete Computational Complexity* (*Computer Research*); (MCS-8202359); $20,362; 12 mos.

The main purpose of this research is to develop efficient algorithms for solving problems in computational geometry. Results in this new and growing research area have various applications in operations research, statistics, computer-aided design, computer graphics, etc. Specific topics studied are: (i) the construction of the weighted Voronoi diagrams and the applications to proximity-related problems; (ii) the shortest path problems with barriers that are represented as polygons or circles; (iii) the off-line insertion-retrieval problem and its applications; and (iv) design of parallel algorithms for geometric problems and their implications. More emphasis will be placed on worst-case analysis of the algorithms, but average-case analysis is also studied.

Iowa State University; Alan L. Selman; *Complexity of Feasible Computations* (*Computer Research*); (MCS-8120263); $40,000; 24 mos.

The computational complexity of feasible computations is studied. The objectives are to reveal the rich structure that individual complexity classes, such as NP, appear to have, and to increase understanding of the structural relations between low level complexity classes. To these ends several techniques are applied.

Properties of polynomial time-bounded reducibilities on NP, and consequences of P = NP and similar hypotheses, are investigated and compared. In addition, applications of these studies are made to problems in cryptocomplexity. Relativization techniques are applied and fundamental issues are raised concerning the import of results about classes relativized to oracles.

The use of counting arguments to obtain nonlinear lower bounds of certain problems in NP are explored. These investigations also involve the applicability of combinatorial techniques from finite model theory.

Louisiana State University; O. Carruth McGehee; *Random Graphs and External Graph Theory* (*Computer Research*); (MCS-8104854); $10,000; 24 mos.(Joint support with Algebra and Number Theory Program-Total Grant $35,300.)

Questions to be investigated include: Hamiltonicity, automorphism groups, and subgraphs in random regular graphs; the diameter of random graphs with few edges; the clique and chromatic numbers of random graphs; and applications of random graphs to certain sorting problems. Professor Bela Bollobas will be the key researcher. The work within these topics belongs to an emerging body of recent work represented by that of Korshunov, Valiant, Shamir, Klee, Larman and Bollobas, among others. In addition, investigations will continue into extremal graph theory and its applications to functional analysis.

Department of the Army; Lawrence Hatch; *A Cryptosystem From Permutation Groups* (*Computer Research*); (MCS-8104206); $30,657; 24 mos.

A new cryptographic system which relies on a method of machine representation of finite permutation groups is studied. Major emphasis is placed on the study of encryption and decryption algorithms based on a space-efficient data structure which is called a logarithmic signature for the group. The total number of keys afforded by the system is of staggering size. Preliminary tests of random number generators based on these techniques show that they satisfy several randomness criteria, including uniformity, cycle-period of arbitrary length, and very low autocorrelations. The questions studied include: construction of random number generators, sampling of very large data sets, randomizing of large data bases, sample splitting, sampling without replacement, generation of large permutations, signature verification, authentication and existence of trapdoor one-way functions in the context of logarithmic signatures.

This project is being funded jointly by the National Science Foundation and the National Security Agency. Dr. Larry Hatch is monitoring the research of Dr. Spyros S. Magliveras and Dr. Alvin J. Surkan at the University of Nebraska-Lincoln.

Harvard University; Harry R. Lewis; *Logic, Decision Problems, and Complexity* (*Computer Research*); (MCS-8005386 A01); $20,675; 24 mos.

The main thrust of the research is a continued investigation of the complexity theory of classical logic. This work has three main goals: to complete the program of comprehending and classifying as completely as possible the effect of various kinds of syntactic restrictions on the expressiveness of logical language; to use these results as a source of examples of more general phenomena in complexity theory; and to apply these results to more specific problems in other areas of computer science, such as the theory of relational data bases.

Harvard University; Michael O. Rabin; *Randomized Algorithms and Concurrent Computations* (*Computer Research*); (MCS-8121431 & A01); $75,885; 12 mos.

Research is concentrated on three interrelating themes centering around randomized algorithms on the one hand and concurrent processes on the other hand: Randomized algorithms for hash functions and pattern matching problems; algorithms for concurrency control and synchronization; concurrent operations on very large data-structures.

The implementation of these algorithms in VLSI is also studied.

Massachusetts Institute of Technology; Albert R. Meyer; *Logic of Programs and Computational Complexity* (*Computer Research*); (MCS-8010707 A02 & A03); $110,911; 12 mos.

The relations among several programming logics in the literature are considered and a study of their comparative expressive power is undertaken. These Logics include Dynamic Logic (Pratt), Algorithmic Logic (Engeler), Algorithmic Logic (Salwicki), Programming Logic (Constable), and Logic of Effective Definitions (Tiuryn). In computational complexity the investigators will consider the relation between the geometry and accessibility of memory structure, and speed of computation.

Massachusetts Institute of Technology; Gary L. Miller; *Studies into the Computational Complexity of Algebraic Problems* (*Computer Research*); (MCS-8007756 A01); $66,922; 24 mos. (Joint support with Algebra and Number Theory Program-Total Grant $79,922.)

This research is concerned with the computational complexity of problems with a strong algebraic component including:

1. Finding an $0(n^{\log^* n})$ time algorithm for graph isomorphism and permutation group intersection using the classification theorem for simple groups, and
2. Finding a polynomial time reduction of factoring integers to that of computing the square free part of an integer.

Massachusetts Institute of Technology; Ronald L. Rivest; *Concrete Computational Complexity* (*Computer Research*); (MCS-8006938 A01); $80,928; 12 mos.

This research is concerned with the study of algorithms and computational complexity in the area of VLSI design and the theory of cryptology. The approach to VLSI design involves developing component packing algorithms and wire routing algorithms subject to the constraints imposed by VLSI manufacturing techniques. The approach to cryptology research involves the development of a conceptual framework that allows the measurement of the security of cryptosystems. This conceptual framework rests upon the development of a theory of "finite" computational complexity.

Northeastern University; Robert J. Lechner; *Harmonic Analysis of Logic Functions I: Encoded Programmable Logic Arrays* (*Computer Research*); (MCS-8108685 A01); $18,294; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $36,587.)

This research is concerned with the development and evaluation of a new unified approach to array logic synthesis using VLSI technology on a scale which applies to software storage as well as to firmware storage and wired control logic within digital systems. Specifically PLAs are imbedded within linear encoding transformations on their inputs and outputs and combined with ROMS as necessary to define more optimal implementations of logic functions or stored tables than are possible with either ROMS or simple PLAs alone. In contrast to more general array logic techniques, the imbedded PLA approach retains the homogeneous array device layout and interconnection topology that reduces design and testing costs.

Heuristic algorithms are developed and tested on realistic examples to evaluate the feasability of the imbedded PLA approach. Theoretical studies are used to evaluate a more rigorous approach to canonical synthesis algorithms that do not require human intervention. A crucial outcome of the study is the identification of that class of functions for which the hybrid (ROM + imbedded PLA) approach to synthesis is more cost-effective than either ROMS or PLAs alone.

University of Minnesota; Sartaj K. Sahni; *Algorithmic Study of Combinatorial Problems* (*Computer Research*); (MCS-8005856 A03); $56,556; 12 mos.

The research is concerned essentially with the study of combinatorial problems, particularly those arising in graph theory, scheduling theory, design automation, and some branches of operations research. Most of the problems that will be studied are known to be NP-hard. Hence, it is very unlikely that any of them can be solved by an efficient (i.e. polynomial time) algorithm. The investigation of these problems will focus on the following issues:

1. Identify large interesting subclasses of the NP-hard problems that can be solved in polynomial time.
2. Obtain good heuristics to solve the problem. i.e., obtain algorithms with a good average behavior.
3. Obtain a characterization of the smallest (or simplest) subclass of the problem that is NP-hard.
4. Obtain good (and fast) approximation algorithms.
5. Obtain subexponential algorithms for the general problem.

University of Minnesota; Dennis E. White; *Representations of the Symmetric Group and Constructive Methods in Combinatorics* (*Mathematical Sciences*); (MCS-8122034); $13,800; 24 mos. (Joint support with the Algebra and Number Theory Program-Total Grant $27,600).

Professor White intends to work on combinatorial aspects of representations of the symmetric group. He plans to continue his work on the relationship between the Littlewood-Richardson rule and the Robinson-Schensted correspondence, relating this to recent work of Schutzenberger. He plans several different extensions of his new interpretation of the Schur function and will further develop his interpretation of the irreducible characters. He will develop further his connections between pattern enumeration, pattern construction, and representation theory. In addition he will continue research on linear orderings of basic combinatorial objects.

Princeton University; Andrea LaPaugh; *Combinatorial Optimization Problems for Object Arrangement* (*Computer Research*); (MCS-8202594); $32,240; 24 mos.

Two classes of problems which involve the optimal arrangement of objects on a plane, circuit layout and rectangle packing, are studied. Each problem in either class is to find a legal arrangement which is optimal under some criterion. Algorithms to solve circuit layout problems are desirable components of VLSI design systems. Rectangle packing problems are motivated by a number of practical tasks, including circuit layout. These classes of problems are also of theoretical interest because most problems in either class are known or suspected to be NP-complete. Therefore, we can only expect polynomial-time algorithms to find good, not optimal, solutions to these problems. The goals in this reseach are:

1. To define versions of the problems which are both solvable in polynomial time and interesting. It is expected that this will be possible only for layout problems, if at all. In this case the most efficient algorithms are studied.
2. To develop and analyze approximation algorithms. Algorithms which provably find solutions within a constant factor of optimal are investigated.

Princeton University; Karl J. Lieberherr; *Combinatorial Optimization and Search Problems* (*Computer Research*); (MCS-8004490 A01); $39,406; 24 mos.

The object of this research is to explore the area of combinatorial optimization and search problems. The general objectives are:

1. To develop and classify general methods for solving combinatorial optimization and search problems and to classify these problems with respect to their complexity.
2. To apply the general methods to the solution of specific practical problems.
3. To compare algorithms obtained with different methods for the same problem and to analyze the algorithms for theoretical and practical efficiency.

Princeton University; Jacobo Valdes and Richard J. Lipton; *Complexity Issues in VLSI* (*Computer Research*); (MCS-8203693); $60,013; 24 mos.

Certain theoretical aspects of Very Large Scale Integration (VLSI) circuits are investigated. The research topics arise from the recent work of the two principal investigators. These topics can be classified into three groups: (1) work on the inherent limitations of VLSI computation (lower bounds), (2) work on the design of new VLSI algorithms and high level models of VLSI computation (upper bounds), and (3) combinatorial problems arising from the problem of designing actual VLSI circuits.

Rutgers University; Ann Yasuhara; *Computability on Term Algebras* (*Computer Research*); (MCS-8009534 A02); $29,527; 12 mos.

The principal investigator is investigating effective methods of computation on finitely generated free (term) algebras that are to be analogous, in each case, to the effective computations on the natural numbers determined by the partial recursive functions. For each case a finitely axiomatizable theory will be found that is just strong enough to represent the class of functions on the particular term algebra computed by the method. Within each such class of functions the investigator wishes to delineate certain subclasses and to relate the various classes to one another in terms of complexity. In terms of the setting thus established the investigator also will consider further work in connection with recursive function theory, logic, finitely presented algebras as congruence classes, relative complexity in terms of coding, and abstract data types.

Cornell University; John R. Gilbert; *Combinatorial Algorithms for Numerical Problems* (*Computer Research*); (MCS-8202948); $38,852; 24 mos.

The thrust of the research is the connections between combinatorial algorithms and numerical analysis. More specifically, graph algorithms are used to aid in the solution of large, sparse systems of linear equations by Gaussian elimination. The tradeoffs between good sparse behavior and good numerical behavior are closely studied. Additionally, numerical methods are used to obtain heuristics for basically combinatorial problems.

Cornell University; Juris Hartmanis; ***Computational Complexity*** (***Computer Research***); (MCS-7800418 A08); $85,983; 12 mos.

This research includes a study of the computational complexity of feasible computations and a related investigation of formally provable computational complexity properties. In particular, the intention is to concentrate on the study of the structure of natural families of computations and the properties and relations between complete problems of these families. As a parallel to this study, will be an investigation of the formally provable properties about complexity of computations and their applications to computational complexity theory.

Cornell University; John Hopcroft; ***Theory of Algorithms*** (***Computer Research***); (MCS-8101220 A01); $87,823; 12 mos.

The research involves investigating practical methods (using probabilistic algorithms) for solving problems for which no polynomial time algorithms are known and investigating applications of theoretical computer science to problems in VLSI design and organization.

State University of New York-Albany; Victor Y. Pan; ***The Computational Complexity of Arithmetic Problems*** (***Computer Research***); (MCS-8203232); $23,442; 12 mos.

Arithmetic computational problems such as Matrix Multiplication and Inversion, DFT, Convolution have important applications. The efficiency of the algorithms for such problems can be measured by their arithmetic complexity, bit-operation complexity, stability, and the complexity of their logical structure. The object of this study is the efficiency of arithmetic algorithms in terms of the criteria listed above and the relationship among the different criteria. Despite the progress in recent study in this area (which was particularly rapid in the study of arithmetic complexity), several important problems remain open. For instance, it is not known if Gaussian elimination is optimal for Matrix Inversion in terms of bit-operation complexity although it is known to be non-optimal in terms of arithmetic complexity. Recently introduced successful techniques and concepts are used as the starting point of this investigation. The results of the study are also applicable to coding and combinatorial problems.

University of Rochester; Joel I. Seiferas; ***Complexity of Algorithms for Storage and Retrieval of Character Strings*** (***Computer Research***); (MCS-8110430); $56,799; 24 mos.

This research involves both string matching and the capabilities of basic abstract storage units.

The string-matching research includes development of time- and space-efficient algorithms for increasingly hard text-searching problems. It also includes proving constraints and lower bounds on the complexity of such algorithms.

To assess the capabilities of abstract storage units, we ask how efficient the possible simulations among them can be. The basic abstract storage units considered include ordinary one-dimensional tapes, pushdown stores, stacks, counters, queues (or buffers), double-ended queues, multidimensional tapes, multihead tapes, and finite sets of these. The entire setting is particularly hospitable to the development of information-theoretic lower-bound techniques.

Duke University; Arnold Rosenberg; ***Graph Embeddings and VLSI Complexity*** (***Computer Research***); (MCS-8116522 A01); $44,226; 12 mos.

The research deals with two subjects that have received considerable attention in the theoretical computer science community over the last several years: graph embeddings and combinatorial aspects of integrated circuitry, especially VLSI.

One problem area to be investigated involves similarity of graph families: one fixes on a specific family of graphs, and one seeks general conditions that guarantee that a given second family of graphs has the same "proximity structure" as the fixed family. Cost tradeoffs in graph embeddings, with applications, will also be investigated.

Finally, the applications of graph embeddings studies for the circuit layout problem will be pursued. In particular, what distortions of grids other than squaring them up (a) may facilitate circuit realization, and (b) can be effected with bounded lengthening of wires and bounded expansion of chip area?

University of Oregon; Stephen T. Hedetniemi and Sandra M. Hedetniemi; ***Towards a Theory of Linear Computation with Recursive Data Structures*** (***Computer Research***); (MCS-7903913 A01); $50,930; 24 mos.

This project focuses on the study of the theory of linear computations, using recursive data structures, which extends previous work by studying techniques for reducing the time and space requirements for processing trees. Several new, compressed data structures for trees will be developed, and their effectiveness will be studied by using them to design algorithms for solving various problems on trees. These algorithms are expected to have faster execution times and smaller space requirements.

The compressed data structures for trees are developed by compressing the recursive representation of a tree, known in the literature as the parent array. The recursive representation results from constructing a tree, beginning with a single vertex, by a finite number of applications of the operation-add a new vertex and join it to an existing vertex in the tree (this vertex serves as the "parent" of the new vertex).

The compressed representations result from altering this construction so that more than one vertex is added during each operation. The following variants of this operation will be studied:

1. Add a path of length k, where k is a random number, to any non-endvertex in the existing tree;
2. Add a set of k independent vertices, where k is a random number, and join each of them to a common endvertex in the existing tree;
3. Add a star with k vertices, where k is a random number, and join the center of the star to an end vertex in the existing tree.

Pennsylvania State University; Greg N. Frederickson; *Tradeoff Issues in Dynamic Data Structures* (*Computer Research*); (MCS-8201083); $39,426; 24 mos.

Data structures that are designed to answer specific types of queries and that also allow efficient insertion and deletion are studied. The tradeoff issues that arise in the implementation of these structures are considered. Among such tradeoffs are time-time tradeoffs, such as those between query and update times. Also studied are time-space tradeoffs, where space is the number of locations used to store the data structure. The work concentrates on identifying both lower bounds and techniques that yield optimal structures. This will shed light on the general issue of resource tradeoffs in data structures.

Southern Methodist University; David W. Matula; *Foundation of Finite Precision Arithmetic* (*Computer Research*); (MCS-8012704 A02); $17,407; 12 mos. (Joint support with the Computer Systems Design Program-Total Grant $34, 813).

Advances in LSI and VLSI capabilities are fostering an era where complex special purpose hardware for specific application areas will be realizable at acceptable costs. The ability to represent all sufficiently simple fractions and to evaluate reasonably small rational expressions exactly are important features making fixed-slash and floating-slash arithmetic interesting possibilities for special purpose architectures. Previous research has demonstrated that fixed and floating-slash systems are sufficiently competitive in arithmetic logic design requirements and representation and timing efficiencies to be serious candidates for special purpose architectures. The research is directed toward developing and assessing the viability of these arithmetic systems in the most promising areas of application: specifically, (i) assessment of the growth of accumulated error in fixed-slash and floating-slash computations; (ii) investigation of the suitability of these systems for incorporation in symbolic computation packages; (iii) for micro and small minicomputer systems; an assessment of the ability of a single firmware level fixed-slash (or floating-slash) arithmetic package to support moderate user level exact integer, exact rational, and approximate real computation capability; and (iv) investigation of enhancements of particularly extended range for floating-slash and algorithms for special purpose functions such as square root.

University of Washington; Victor L. Klee; *Convexity, Complexity and Combinatorics*; (MCS-8116069); $9,000; 12 mos.(Joint support with the Algebra and Number Theory Program-Total Grant $26,650).

Professor Klee will continue research in the areas of convex sets, optimization, computational complexity, and combinatorics. In particular, his attention will fall on questions related to sign quasistability for real square matrices; diameters of random bipartite graphs; relative minima among triangles containing a given convex polygon; the d-step conjecture in the combinatorial structure of convex polytopes; decision-tree complexity; computational complexity for convex polyhedra; tilings of infinite-dimensional normed linear spaces; uniform properties of convex bodies; preference relations and utility functions; and minimum graphs. Much of the work will be done in conjunction with students and colleagues.

University of Washington; Richard E. Ladner; *Theory of Advanced Computing Structures* (*Computer Research*); (MCS-8003337 A02); $68,047; 12 mos.

The investigator will develop theory in several practical areas of computing. Goals are to find good abstract models, improved and inherent limitations. Particular topics to be studied include communicating processes, very large scale integrated circuits (VLSI), text editing, and time and space requirements of natural problems.

Washington State University; Karl Winklmann; *Information-Flow Characteristics of Combinatorial Problems* (*Computer Research*); (MCS-8202964); $28,000; 24 mos.

The following research is pursued:

1. Formalize a measure of "inherent nonlocal character" of combinatorial problems, drawing on existing work on information flow in distributive computing.
2. Applying the new measure to a variety of combinatorial problems to see how the resulting classification meshes with the standard P-vs.-NP classification.
3. Attempt to translate lower bounds on the "inherent nonlocal character" of combinatorial problems into lower bounds on their computational complexity.

This approach to computational complexity attempts to derive lower bounds by playing the "inherent nonlocal character" of combinatorial problems against the necessarily "local" character of computation, i.e., the fact that algorithms do not "look at the whole picture" to decide on the next step. Relativization results are of little concern in this approach since oracle computations are highly "nonlocal." (Oracles "look at" unbounded amounts of information when deciding on an answer.) This contrast with the classical diagonalization-based approach to lower bounds is a major motivation behind the proposed work.

Univ. of Wisconsin-Madison; Samuel W. Bent; *Dynamic Weighted Data Structures* (*Computer Research*); (MCS-8203238); $31,998; 24 mos.

Dynamic Weighted Data Structures provide flexible and efficient access to ordered collections of items with non-uniform reference frequencies. They support a variety of dynamic operations that alter the size of a collection or the weights of items within a collection, while maintaining the weighted access time to all items in a collection to within a constant of optimal. The optimal weighted access time (and hence the achieved weighted access time) and the time required for each dynamic operation are related to the entropy of the distribution of reference frequencies. The frequencies can either be given as input, or derived from the pattern of reference to the items.

The properties of dynamic weighted data structures are studied. The study focuses on their theoretical properties in an attempt to understand how to create dynamic weighted structures from dynamic unweighted structures. In addition, the study examines the nature of amortizing algorithms, that is algorithms for performing a sequence of elementary operations (such as the dynamic operations for a data structure) for which the running time for the entire sequence can be bounded, but for which the time for the individual operations cannot.

Parallel, Distributed, and Data Base Models

Stanford University; Zohar Manna; *Temporal Verification and Synthesis of Concurrent Programs* (*Computer Research*); (MCS-8111586 A01); $53,252; 12 mos.

Temporal Logic has been found to be a useful and powerful formalism for the analysis of concurrent programs. It is proposed to continue research aiming at developing the temporal methodology into a practical verification and synthesis tool. The ultimate goal is to construct an experimental Temporal Logic verifier for concurrent programs, and to establish a temporally based methodology for synthesis of concurrent programs.

University of California-Irvine; Daniel S. Hirschberg; *Parallel Algorithmic Techniques* (*Computer Research*); (MCS-8200362); $31,435; 24 mos.

The goal of this project is to investigate techniques for implementing algorithms efficiently on a parallel processing system. The development of a suitable realistic model of computation and the development of algorithms for this model that are fast yet have minimal resource requirements are emphasized. Previous work on this project considered parallel algorithms for graph algorithms. These basic algorithms could be used as subroutines in solving a variety of problems. The model for parallel computation assumed that any number of processors could simultaneously have fetch access to the same location within a large global area. While this model is somewhat theoretic, the algorithms contribute to the basic understanding of how to develop efficient parallel algorithms. A more practical result of this effort was the development of a bucket sort algorithm that assumes a model of computation where no more than one processor can access any one location simultaneously. This research project will continue to introduce further modifications to the model of computation that will result in simulating reality more closely. It will take more factors into the cost accounting, while retaining the capability of complexity analysis.

Georgia Institute of Technology; Richard A. DeMillo, Kimberly N. King, and Raymond E. Miller; *Models of Computation and Algorithms* (*Computer Research*); (MCS-8103608 A01); $99,825; 12 mos.

Theoretical research will be performed on models of computation. In the area of parallel models and concurrency, two projects will be undertaken; one project introduces the notion of stochastic synchronization and will clarify properties of contention-based synchronization, while the other project is a comparative study of models of parallel computation. In the area of more conventional models a number of problems are addressed: computational complexity of alternating machines, logical independence, VLSI algorithms, and combinatorial graph embeddings.

Harvard University; Harry R. Lewis; *Parallel and Probabilistic Computation* (*Computer Research*); (MCS-8200269); $113,455; 24 mos.

The computational power of various abstract machines which employ parallelism, random choice, and/or probabilistic acceptance is studied. These computational models are studied both for their significance to the foundations of computer science, and for their ability to solve efficiently specific problems of natural interest and practical significance. Algorithms resulting from this study will enable problems to be solved that previously required infeasible amounts of computational resources.

Massachusetts Institute of Technology; Christos H. Papadimitriou; *Algorithms, Complexity and Database Theory* (*Computer Research*); (MCS-8120181); $54,119; 24 mos.

Research is performed in combinatorial optimization, VLSI theory, and database theory. In combinatorial optimization the existence of "strongly" polynomial algorithms for linear programming and several questions related to integer programming are investigated. In VLSI two new directions of research related to lower bounds for on-chip computation are investigated. In database theory research in concurrency control (including some applied work for validating underlying assumptions), and the problem of distributed query processing are studied.

New York University; Marc Snir; *Communication Complexity of Parallel Algorithms* (*Computer Research*); (MCS-8203307); $30,000; 24 mos.

Future ultralarge machines will probably be built from powerful VLSI components interconnected with few, relatively slow lines. The complexity of parallel algorithms in a model fitting this type of machine is investigated. In such a model the complexity of algorithms is measured by the number of communication steps.

Several techniques are suggested to prove lower bounds on the complexity of algorithms in this model. Preliminary results have been obtained for search algorithms and for some arithmetic computations, and these results are extended and new techniques are explored.

Algorithms suited for a parallel machine with a large communication bandwidth between processors but with long delays for interprocessor communication and synchronization are also studied.

State University of New York-Albany; Seth Chaiken; *Matroids, Electrical Networks, and Algorithms* (*Computer Research*); (MCS-8204796); $37,566; 24 mos.

The object of this project is the investigation and elucidation of the interplay between combinatorics and electrical network (and other dynamical system) theory. Matroid theory is the focus of the study in combinatorics.

The following aspects of network theory are investigated: those that are purely combinatorial; those for which metrical and sign aspects can be abstracted to combinatorial theory; and those for which aspects of full numerical analysis are necessary to obtain information. The theory of oriented matroids and electrical networks will be studied in terms of the linking systems or bimatroid axiomatization of matroid theory.

Models suitable for the study of matroid computational problems and algorithms are investigated. An investigation of how algorithms can take advantage of metrical and sign aspects of electrical and other problems is also conducted. Finally, the graph problem of deciding which pairs of edges occur with the same relative orientation in every circuit that contains them both is studied.

University of Rochester; Gary L. Peterson; *The Design and Complexity of Concurrent Control Algorithms* (*Computer Research*); (MCS-8202950); $20,000; 24 mos.

The design of efficient algorithms for concurrent control problems in systems of asynchronous processes is one of the most difficult and important areas in computer science. Theoretical analysis of such problems from the point of view of complexity is adding to our knowledge of what can be solved and how efficiently. The research aims toward developing formal models for realistic systems of processes, such as local networks, as a basis for complexity analysis. Problems which highlight the complexity issues involved are developed as a step toward forming a complexity theory for concurrent control problems. Important individual problems are analyzed so that upper and lower bounds on resources such as space and time can be given. The techniques for determining such bounds are to be expanded. The final result will be a better understanding of the nature of asynchronous computation and control in addition to algorithms and techniques for the design of algorithms that are useful to the practitioner.

Brown University; Jeffrey S. Vitter; *The Analysis and Implementation of Algorithms for Information Retrieval* (*Computer Research*); (MCS-8105324); $33,834; 24 mos.

This research is concerned with developing and evaluating efficient methods for large-scale information retrieval, with applications to database systems. The research centers on algorithms of fundamental importance that are (or soon will be) in widespread use, namely, coalesced hashing, multidimensional k-d trees, and relational database algorithms for associative devices. The goals are to resolve the open problems concerning their implementations and to design and compare new variants, based on precise mathematical analysis.

Foundations of Computer Science

SRI International; Joseph A. Goguen; *Exceptions and Non-Termination for Abstract Data Types-Partial and Continuous Algebras* (*Computer Research*); (MCS-8201380); $48,941; 24 mos. (Joint support with the Software Systems Science Program-Total Grant $97,881).

The goal of this research is to extend present algebraic specification techniques, which have so far been largely applied to the specification of discrete data structures, so as to encompass abstract control structures (e.g., do-while and backtracking), computations which do not necessarily terminate (e.g., operating systems), exception (or error) handling and recovery, and infinitary data structures. The effectiveness of solutions, and in particular the computability and proof theory of infinitary and error data structures, and their relationship with "direct" implementations by rewrite rules, are investigated. Implications of the findings for programming methodology are also studied, and in particular, suitable extensions for the specification language CLEAR and its semantics are developed.

Extending and parameterizing abstract data types give rise to delicate problems of consistency, especially in the context of exceptions and non-termination, which are part of the investigation.

Stanford University; Vaughan R. Pratt; *Logical Methods for Program Analysis* (*Computer Research*); (MCS-8205451); $60,746; 12 mos.

The research concerns the application of logical methods to the automatic analysis and management of storage, types, statistics, communication, dynamics, and checkpointing of dataflow programs. The work consists of the development of decision methods for fragments of logic tailored to the applications.

University of Southern California; Seymour Ginsburg; *Mathematical Foundations of Databases* (*Computer Research*); (MCS-7925004 A01); $96,959; 24 mos.

This study is concerned with theoretical aspects of databases. The relational database model is extended in order to take advantage of naturally occurring semantic constraints. The algebraic properties of these constraints are studied and applications to database efficiency and the physical design of database machines are explored.

Yale University; Dana C. Angluin; *Algorithms for Inductive Inference* (*Computer Research*); (MCS-8002447 A02); $105, 500; 24 mos.

The research is in the area of algorithms for inductive inference. The questions focused on are:

1. special classes of languages and functions that are efficiently inferrable;
2. formal analysis of constructive inference procedures;
3. inference of languages from positive-only data;
4. development of a general definition of the complexity of inference;
5. adaptability of inference procedures to new domains;

6. inference and the synthesis of logic programs;
7. inference algorithms for a text-editing application.

Purdue University; Paul R. Young; *Mathematical Theory of Computation* (*Computer Research*); (MCS-8119866); $57,146; 12 mos.

Research is pursued in three areas:

1. Independence results for computer science.
2. The power of nondeterminism in the computation of discrete functions.
3. Analytic computational complexity.

The first two areas are concerned with discrete computational complexity while the third is concerned with the computation of real valued functions. Strong independence results would suggest that P=NP is dependent on the model of computation chosen, solutions in the second area would refine such computational models, while solutions in the third area would extend complexity results to computable real numbers and real analysis.

University of Maryland-Baltimore County; Arthur G. Werschulz; *Analytic Computational Complexity* (*Computer Research*); (MCS-8203271); $15,852; 24 mos.(Joint support with the Software Engineering Program-Total Grant $25, 852).

Analytic computational complexity is that area of applied mathematics and theoretical computer science which seeks to determine the minimal cost of solving a given class of problems, the problem class having the property that no finite-cost algorithms exist for its exact solution. The Investigator's previous research has mainly been in this area, covering problems in numerical quadrature, differentiation, and the solution of differential equations, as well as the solution of general abstract problems. The Investigator is studying a number of new problems in this area, such as the effect of model of computation on the quadrature problem, the removal of certain restrictions (e.g., zero boundary data) on elliptic boundary-value problems, the complexity of non-elliptic partial differential equations, more intensive study of optimality properties of finite-element methods, characterizing optimal-complexity functions, and the role of regularity in general Banach-space problems.

Boston University; Rohit J. Parikh; *Logics of Programs* (*Computer Research*); (MCS-8109102); $24,770; 12 mos.

Research on logics of programs is pursued. Particular emphasis is placed on (i) Applications of Process Logic to actual examples, specifically to parallel computation (ii) Developing a logic for probabilistic computations. (iii) Studying the relationship and similarity between Dynamic Logic and Denotational Semantics. (iv) Studying the computational complexity of programs and the strength of the logics used to prove their termination properties.

City University of New York-Brooklyn College; Attila Mate; *Orthogonal Polynomials and Computational Complexity* (*Mathematical Sciences*); (MCS-8100673 A01; $8,000; 24 mos. (Joint support with the Topology and Foundations Program-Total Grant $31,795).

Work in classical analysis, logic and theoretical computer science will be done.

The main interest in classical analysis is the application of various techniques of estimation to the study of orthogonal polynomials. Improvements of an asymptotic estimate obtained with P. G. Nevai for the arithmetic mean of the first n orthogonal polynomials on the unit circle with respect to a measure belonging to the Szego class will be sought. This would have several applications in probability and statistics. Investigations into the relationship between the second order recurrence equation satisfied by orthogonal polynomials and the associated measure will be carried out. These problems naturally lead to questions involving polynomial inequalities and the asymptotic behavior of difference and differential equations. Of particular interest is the improvement of a polynomial inequality recently obtained with P. G. Nevai that estimates the value of a polynomial on the unit circle with integrals of powers of its absolute value.

Explorations of nonstandard models of arithmetic used to study questions of computational complexity will be made. In particular the question of whether nondeterministic polynomial time computations are more powerful than deterministic ones will be taken up. The investigation of certain partial extensions of nonstandard models of arithmetic may shed some light on this question.

Clarkson College of Technology; James F. Lynch; *Problems in Finite Model Theory* (*Computer Research*); (MCS-8002695 A01); $27,937; 24 mos.

The close connection between finite models and the complexity of computational problems is investigated. Two topics are studied. The first concerns the definability of sets by logical sentences and the corresponding acceptance problems using restricted Turing machines.

The second concerns the asymptotic behavior of probabilities of sentences (i.e., the probability that a finite model satisfies a sentence). Typical results in the second area concern the impossibility of defining properties of models by using the relation, "is a model of," restricted to finite models. Such results lead to new techniques for obtaining computational complexity results.

Cornell University; Robert L. Constable and Alan J. Demers; *On Logics for Program Development* (*Computer Research*; (MCS-8003349 A01); $64,500; 12 mos. (Joint support with the Software Engineering Program and Software Systems Science Program-Total Grant $224,981).

This research involves the judicious combination of the strong points of program development methodology and program verification in a logic for correct program development. This project will explore a logic of formal top down development, called a refinement logic. During the grant period a prototype system will be designed and built. This system will be used in extensive experimentation of the refinement logic concept. Comparisons with other systems will also be conducted.

New York University; Martin Davis and Elaine J. Weyuker; *Theoretical Investigations in Computer Science*; (MCS-8201167); $45,000; 24 mos.(Joint support with the Software Engineering Program-Total Grant $115,000).

This research includes continuing work on improved algorithms for the satisfiability problem, a problem that has played a central role in computational logic and in the theory of complexity of algorithms. Workers in artificial intelligence have introduced non-monotonic systems of logic intended to model aspects of everyday human inference not covered by classical logic. It is planned to investigate relations between semantic and proof-theoretic aspects of such systems. Interesting theoretical problems arise in attempts to gain insight into the question of what constitutes an "adequate" set of data for testing a computer program before it is released for general use. Continued work seeks axiomatic characterizations of adequacy and studies the properties of one notion of adequacy based on program length. This last notion leads to a lower bound on the amount of data needed to test a given program.

Automata and Language-based Models

University of Alaska-Fairbanks; Thomas J. Head; *Codes in Formal Language Theory* (*Computer Research*); (MCS-8003348 A01); $28,832; 12 mos.

Code properties of classes of languages and relations are studied. It has been observed that it is decidable whether a regular language is a code. Extensions of this decidability result to more general types of linear and context free languages, and to additional types of Petri net languages, are pursued.

Relations that are codes are also investigated. Procedures for deciding whether a finite binary relation is a code are studied.

Finally, special hypercodes contained in DOL languages are studied in order to determine if the results can be generalized.

Stanford University; John R. Perry; *Computational Aspects of Situation Semantics* (*Computer Research*); (MCS-8211902); $23,128; 24 mos. (Joint support with the Intelligent Systems and Information Science and Technology Programs-Total Grant $69,263).

Situation semantics is a mathematical theory of linguistic meaning that grew out of artificial intelligence work in natural language processing. The goals of research in situation semantics include developing computationally feasible procedures for natural language understanding systems, developing the mathematical theory of situation semantics, and comparing the efficiency of situation semantics to more standard approaches to the theory of linguistic meaning. This is a joint research project with Professor Barwise at the University of Wisconsin-Madison.

University of California-Santa Barbara; Ronald V. Book; *Computational Complexity and Formal Languages* (*Computer Research*); (MCS-8011979 A04); $13,214; 0 mos.

Term-rewriting systems that are useful in automatic theorem proving applications are studied. Two types of term-rewriting systems are investigated:

1. Term-rewriting systems that are confluent and Noetherian with infinite reduction sets for which each term has a finite reduction sequence.
2. Non-Neotherian and/or non-confluent term-rewriting systems with decidable reduction procedure.

Attention is focused on the computational complexity and formal language aspects of these systems.

This grant supports the summer research of Professor Donald H. Potts, a small college faculty member at California State University, Northridge.

University of Delaware; Thomas J. Myers; *Transformations on Conditional Rewriting Systems* (*Computer Research*); (MCS-8113250); $26,048; 24 mos.

Research is directed toward developing a theory of conditional rewrite rules and investigating certain aspects of program transformations, in particular the introduction of parallelism.

More specifically, we:

1. investigate the formal properties of conditional equations and conditional rewrite rules, as well as compare their pragmatic advantages or inconveniences over unconditional rules.
2. formalize and extend program manipulations using the results of studies of rewrite rules as a basis.

This research is performed in collaboration with Dr. Jean Gallier of the University of Pennsylvania.

Johns Hopkins University; S. Rao Kosaraju; *Applications of Foundations of Computing* (*Computer Research*); (MCS-8205167); $44,974; 12 mos.

The objective of this research is the investigation of the applicability of principal theoretical tools developed in foundations of computing to more practical problems in computer science. The problems selected are from the design of sequential and parallel algorithms, mesh networks, VLSI, redistribution of computations in algorithms, and coding theory.

In the area of parallel algorithms, the research will focus on problems pertinent to VLSI such as the comparative power of networks and embeddings leading to efficient layout, and problems derived from the unbounded parallelism model. Research in mesh networks will emphasize algorithm design and properties of network topologies. Mesh designs are extremely useful for VSLI, so these separate areas are closely interrelated. In addition, the investigator will pursue the advantages of redistributing computations to increase the efficiency of algorithms. Finally, coding theory will be investigated as a technique in algorithm design.

Boston University; Steven Homer; *Non-Linear Recurrence Relations, Quadratic Automata and Applications* (*Computer Research*); (MCS-8218383); $12,459; 22 mos.

Quadratic automaton transformations, the input/output of quadratic automata, have been seen to yield concise algebraic representations. These representations lead naturally to quadratic recurrence relations about which little is known. Questions concerning the solutions to such recurrences are considered with the prospect of applying known methods from linear recurrence theory. The theoretical study of quadratic automata, shift registers, and recurrence relations will both produce satisfying and beautiful results and have valuable applications to quadratic codes and to communications and systems theory.

Massachusetts Institute of Technology; John V. Guttag (in collaboration with Deepak Kapur and David R. Musser, General Electric Company); *Joint Industry/University Cooperative Project To Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8119846); $18,733; 12 mos. (Joint support with the Software Systems Science and Software Engineering Programs-Total Grant $56,198).

This joint industry/university cooperative project involves the construction of a rewrite rule laboratory. Rewrite rule systems have come into use in a variety of fields of computer science. They are being used in automated theorem provers, in high level languages, and in software engineering applications. The rewrite rule laboratory allows the computer scientist to develop efficient algorithms for rewrite systems, allows for instrumentation of rewrite systems, allows the comparison of rewrite systems, and allows the development of rewrite systems useful in software engineering, automated theorem proving, and high level language development.

The system is being constructed at the General Electric Laboratories in Schenectady, New York and at the Laboratory for Computer Science at the Massachusetts Institute of Technology. Upon completion the system will be distributed to all interested parties.

Williams College; Kim B. Bruce; *Models of Typed and Untyped Lambda Calculus* (*Computer Research*); (MCS-8202851); $30,621; 24 mos.

Models of the typed and untyped lambda calculus with applications to denotational semantics are studied. Recursive domain equations arise in specifying the denotational semantics of programming languages. The focus is on algebraic rather than categorical methods for both defining and constructing models of the typed lambda calculus (and hence for solving domain equations). The approach is in the same spirit as Meyer's work on models of the untyped lambda calculus. The relationship of this algebraic approach to the category-theoretic approach is examined and the two are tied together. Further work involves the study of the structure of models of untyped calculus. This includes such questions as the uniqueness of expansion from combinatory algebras to lambda algebras and other similar questions.

General Electric Company; Deepak Kapur and David R. Musser (In collaboration with John V. Guttag, Massachusetts Institute of Technology); *Joint Industry/University Cooperative Project To Build "A Rewrite Rule Laboratory"* (*Computer Research*); (MCS-8211621); $11,704; 12 mos. (Joint support with the Software Systems Science and Software Engineering Programs-Total Grant $35,110).

This joint industry/university cooperative project involves the construction of a rewrite rule laboratory. Rewrite rule systems have come into use in a variety of fields of computer science. They are being used in automated theorem provers, in high level languages, and in software engineering applications. The rewrite rule laboratory allows the computer scientist to develop efficient algorithms for rewrite systems, allows for instrumentation of rewrite systems, allows the comparison of rewrite systems, and allows the development of rewrite systems useful in software engineering, automated theorem proving, and high level language development.

The system is being constructed at the General Electric Laboratories in Schenectady, New York and at the Laboratory for Computer Science at the Massachusetts Institute of Technology. Upon completion the system will be distributed to all interested parties.

University of Pennsylvania; Jean H. Gallier; *Transformations on Conditional Rewriting Systems* (*Computer Research*); (MCS-8111726); $34,264; 24 mos.

Research is directed toward developing a theory of conditional rewrite rules and investigating certain aspects of program transformations, in particular the introduction of parallelism.

More specifically, we:

1. investigate the formal properties of conditional equations and conditional rewrite rules, as well as compare their pragmatic advantages or inconveniences over unconditional rules.
2. formalize and extend program manipulations using the results of studies of rewrite rules as a basis.

This research is performed in collaboration with Dr. Thomas Myers of the University of Delaware.

University of Washington; Robert W. Ritchie; *Toward Automated Natural Language Processing: Phrase Linking Grammars for Syntax and Semantics* (*Information Science*); (IST-8118393); $15,323; 12 mos. (Joint support with the Intelligent Systems and Information Science and Technology Programs-Total Grant $101,184).

This research project is focused on the characterization and understanding of natural language. An information structure called the "linked tree" is being used as a representation which will allow a syntactic and a semantic interpretation of natural language as well as the process of understanding natural language.

The investigators are particularly interested in the development of a restricted syntactic theory that is adequate to allow a revealing description of any natural language; and integration of semantics with syntax; a formulation of a theory of parsing and interpretation that is consistent with available psycholinguistic evidence; and insight into the exploitation of parallelism to study the complexity of language.

University of Wisconsin-Madison; K. Jon Barwise; *Computational Aspects of Situation Semantics* (*Computer Research*); (MCS-8201940); $17,537; 24 mos.(Joint support with the Intelligent Systems and Information Science and Technology Programs-Total Grant $52,609).

Situation semantics is a mathematical theory of linguistic meaning that grew out of artificial intelligence work in natural language processing. The goals of research in situation semantics include developing computationally feasible procedures for natural language understanding systems, developing the mathematical theory of situation semantics, and comparing the efficiency of situation semantics to more standard approaches to the theory of linguistic meaning. This is a joint research project with Professor Perry at Stanford University.

Computer Research Equipment

University of Delaware; Peter J. Warter and B. F. Caviness; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203947); $175,000; 12 mos. (Joint support from the Computer Systems Design Program, Software Engineering Program, Intelligent Systems Program, and Special Projects Program).

This grant provides partial support for a minicomputer system upgrades to an existing system, and their interconnection into a local network system. This equipment supports research in the following areas:

1. Computer Algebra,
2. Distributed Processing and Networking,
3. Natural Language Processing,
4. Computer Architecture for All Points Addressable Displays, and
5. Digital Image Processing.

University of Central Florida; Terry J. Frederick; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203867); $94,161; 12 mos. (Joint support from the Software Engineering Program and the Computer Systems Design Program).

This grant is for partial support of a mini computer system which will form the basis for a Computer Systems/VLSI Design Laboratory. This equipment supports research in the following areas:

1. Dynamic Microprogramming,
2. Source-level Program Analyzers, and
3. VLSI Design Tools.

University of Hawaii-Manoa; W. Wesley Peterson ; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203811); $19,852; 12 mos.(Joint support from the Theoretical Computer Science Program and the Software Engineering Program).

This grant partially supports the development of a microcomputer software laboratory consisting, initially, of five microcomputers connected in a network with one of them providing network services. This laboratory will support existing and future research projects, including work in the development of the network service and in the areas of human processing of computer languages, proof checking by computer, complexity of algorithms, and decision table programming.

University of Illinois-Urbana; David L. Waltz and Thomas S. Huang; *Computer Science and Computer Engineering Research Equipment*; (MCS-8204253); $141,581; 12 mos. (Joint support from the Computer Systems Design Program and the Intelligent Systems Program).

This grant provides partial support for two minicomputer systems in support of research in the following areas:

1. Reliable, High Performance VHSIC Systems
2. 3-D Modelling
3. Expert Systems & Mechanism Understanding
4. Schema Acquisition in a Natural Language Processing System
5. Automated Expert Skill Improvement from Observation & Practice
6. Dynamic Scene Analysis with Applications to Robotics & Other Areas
7. Natural Language Access to a Large Data Base
8. Understanding Natural Language Scene & Event Descriptions
9. Advanced Information Retrieval Interface Design.

University of Massachusetts; Victor R. Lesser and Edward M. Riseman; *Computer Science and Computer Engineering Research Equipment*; (MCS-8204251); $175,000; 12 mos. (Joint support from the Software Systems Science Program, Software Engineering Program, Intelligent Systems Program, and Special Projects Program).

Two minicomputers, communications and networking equipment and a hard copy printer, are being obtained in support of research in the following areas:

1. Vision & Robotics,
2. Cooperative Distributed Problem Solving,
3. Expert Systems,
4. Text Retrieval & Office Automation, and
5. An Integrated Software Development System.

Michigan State University; Harry G. Hedges; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203862); $113,902; 12 mos. (Joint support from the Computer Systems Design Program, Software Engineering Program, Intelligent Systems Program, and Special Projects Program).

A large minicomputer is being obtained to support research in the following areas: 1. Pattern Recognition and Image Processing; 2. Distributed Computer Systems; and 3. Parallel Processing.

State University of New York-Buffalo; Patricia J. Eberlein; *Computer Science and Computer Engineering Research Equipment*; (MCS-8206397); $34,480; 12 mos. (Support from Intelligent Systems Program).

This grant supports the acquisition of additional memory, a printer, and terminals for attachment to an existing minicomputer. This equipment will be used on the following research projects:

1. A Belief Revision System Based on Heterarchical Contexts;
2. Computer Representation of Multidimensional Digital Images; and
3. Contextual Algorithms for Text Recognition.

State University of New York-Stony Brook; David R. Smith and Arthur J. Bernstein; *Computer Science and Computer Engineering Research Equipment Program*; (MCS-8203955); $64,743; 12 mos. (Support from Computer Systems Design Program and the Special Projects Program).

This grant supports the purchase of computer related modules for interconnection into experimental computer networks. This equipment supports research in the following areas:

1. Experiments with tree-organized separated memory multiprocessors;
2. The Design and Implementation of a Network Computer; and,
3. Portable Operating & Debugging Systems for Network Computers.

Oregon State University; Fred M. Tonge; *Computer Science and Computer Engineering Equipment*; (MCS-8112087); $106,950; 12 mos. (Joint support from Theoretical Computer Science Program, Computer Systems Design, and Intelligent Systems).

A large scale minicomputer system is being obtained to support research on:

1. An intelligent tutorial system for interactive problem solving;
2. Empirical investigators of graph theory applications;
3. A personal database system;
4. A distributed computer system testbed, and;
5. Formal approaches to natural language understanding.

Pennsylvania State University; Mary J. Irwin; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203793); $55,653; 12 mos. (Support from Computer Systems Design Program).

Additional computer memory and other equipment for their current computer system will be obtained to perform research in the following topics:

1. VLSI systems design for matrix computation
2. Digit online networks for recursive problems
3. Structure of digit online networks.

University of Pittsburgh; John P. Kearns; *Computer Science and Computer Engineering Research Equipment*; (MCS-8206235); $24,890; 12 mos. (Joint support from the Theoretical Computer Science Program, Software Systems Science Program, and Computer Systems Design Program).

Computer research equipment will be obtained to allow research in the following areas:

1. VLSI Systems for-genetic-algorithm based learning systems;
2. Memory management studies;
3. Efficient algorithms for PLA folding;
4. Studies in control implementation.

University of Washington; Jean-Loup Baer; *Computer Science and Computer Engineering Research Equipment*; (MCS-8204822); $60,000; 12 mos. (Joint support from the Software Systems Science Program, Computer Systems Design Program, Intelligent Systems Program, and Special Projects Program).

A high quality color raster scan display is being acquired to support research in the following areas:

1. Hierarchical Parallel Image Processing;
2. VLSI Design Automation; and
3. Document Preparation and Office Automation.

Washington State University; Narsingh Deo; *Computer Science and Computer Engineering Research Equipment*; (MCS-8203868); $146,512; 12 mos. (Joint support from the Theoretical Computer Science Program, Computer Systems Design Program, Software Engineering Program, and Intelligent Systems Program).

A large scale minicomputer system is being acquired to support research in the following areas:

1. Expert system specification;
2. Parallel processing of graphs;
3. Efficient algorithms for shape recognition;
4. The average-case behavior of approximation algorithms;
5. The generation and use of random variables in computers; and,
6. Simulation of multiprocessor systems.

Coordinated Experimental Research

Experimental Computer Research

University of California-Los Angeles; Gerald Estrin, Algardis Avizienes, Leonard Kleinrock and Gerald Popek; *An Advanced Network Environment for Distributed Systems Research*; (MCS-8121696); $850,552; 12 mos.

This award will aid in the establishment of a major experimental facility to support a program of research on advanced distributed computing systems and their applications. The facility will include a local-area computer network containing a small number of powerful computers, a large number of flexible minicomputers, and special purpose peripheral equipment.

This experimental facility is intended to immediately support investigations of the applications of distributed systems, as well as studies of the fundamental architectural issues of such systems. Results in both these directions will be returned to the facility itself in the form of evolutionary enhancements. The facility is at once both an object of and a tool for advanced experimental computer science research.

A variety of research projects are planned and underway. The proposed research program encompasses: distributed operating systems and distributed databases; performance of new distributed architectures and systems; distributed simulation of network architectures; innovative architectures and fault tolerance; performance evaluation of multiprocessor systems; system design tools and user application interfaces.

Yale University; Martin Schultz, Alan Perlis, and Roger C. Schank; *An Attached Processor Systems Laboratory*; (MCS-8106181 A01); $673,280; 12 mos.

This award will aid in the establishment of a major experimental facility to support research in numerical analysis, scientific computing, algorithms, array processing, computer architecture, artificial intelligence, natural language processing, and systems programming. These new resources will enhance their computational capability and overcome address-space limitations which restrict their natural language research. They will also add a powerful array processor to support scientific computing and specialized processors for the LISP programming language. All these resources will communicate over a high bandwidth network, while terminal access will be provided through a switching network.

The completed local network of sophisticated computing resources will support cooperative research among three major research groups: the systems programming group, the scientific computing group, and the artificial intelligence group. The scientific computing group will concentrate on new algorthims and architectures, such as attached processors, to find ways to dramatically increase the scale of problems which can be considered for computer solution. The artificial intelligence group will pursue studies of integrated understanding and memory by modelling human memory organization and search strategies. Besides pursuing interests in distributed computing, the systems programming group will make major contributions to the others by bringing their experience to bear on the problems of supporting attached processors and implementing interactive problem understanding environments.

University of Illinois-Urbana; David Kuck and Charles W. Gear; *A Computer and Software Systems Design Laboratory*; (MCS-8105896 A01); $807,253; 12 mos.

This award will aid in the establishment of a major experimental facility to support research and development of computer aids to the design of computer and software systems. The project will result in the development of methodologies, techniques and software for supporting various aspects of computer science research. Joint studies by computer science researchers of various backgrounds will be facilitated.

The facility will expand on current departmental resources adding three major computational resources and a supporting high bandwidth network to interconnect the current and new resources. Highly interactive access will be provided through user interfaces and a switching network. Terminals can be directly connected to a particular resource through the switching network while user and process communication is maintained over the high speed network.

A variety of research projects are planned and underway in four major areas, theoretical foundations, algorithm implementation, support software, and run-time systems. The topics include: theory of computation, creation of scientific software, VLSI technology, computer architecture, compilers, databases, inductive inference and conceptual data analysis, and software systems research. The enhanced facility will serve as a catalyst for cooperative and productive research.

Cornell University; Robert L. Constable, Richard W. Conway, David J. Gries, and Alan J. Demers; ***A Laboratory for Experiments on the Programming Process***; (MCS-8105763 A01); $442,080; 12 mos.

This award will aid in the establishment of a major experimental facility to support research on the programming process at Cornell University. The investigators will consider a variety of topics including programming environments, the discipline of programming, and language design and implementation. While having distinct goals and clearly separate approaches the high degree of interaction among the researchers should provide results which strongly impact our understanding of programming.

The facility will include a variety of current and new computational resources interconnected by a local area network. While each researcher may access specialized resources for a particular project, all resources will be available to each user of the network. This environment can provide excellent communication between research projects while matching the appropriate resource to an individual project. Cornell has been characterized as being engaged in highly individualized computer science research in an atmosphere of close rapport. This facility will enhance the research opportunities while maintaining this highly productive environment.

Brown University; Andries van Dam, Thomas Charniak, Thomas W. Doeppner, Paris C. Kannellakis, Steven P. Reiss, John E. Savage, Robert Sedgewick, Jeffrey S. Vitter and Peter Wegner; ***An Integrated Environment for Research in Computer Science***; (MCS-8121806); $531,726; 12 mos.

This award will aid in the establishment of a major experimental facility to support a program of research in computer science. The facility will include a local-area computer network containing a powerful minicomputer, a large number of personal computers, and special purpose peripheral equipment.

The investigators will develop a computing environment for the effective use of this network of powerful personal computers. At the core of this environment will be a powerful set of graphics tools. These tools will allow each researcher to customize a graphics-oriented user interface to a specific research project. A database management framework and system will underlie and support the graphics tools.

Research in graphics, databases and operating systems will be key to developing a stable and useful system. The investigators will provide the graphics tools to the larger research community for assistance in guiding refinements and revisions. Other research by the investigators in algorithms, artificial intelligence, compilers, document preparation, learning environments and other areas has made good use of existing tools. The interaction between this research and that connected with the facility itself will also lead to improvements and new research directions.

William Marsh Rice University; Kenneth W. Kennedy, Robert Cartwright, John Dennis and J. Robert Jump; ***An Experimental Computer Network to Support Numerical Computation***; (MCS-8121884); $416,971; 12 mos.

This award will aid in the establishment of a major experimental facility to support a program of research on advanced distributed computing systems and numerical computing. The Rice Numerical Network, or R^n, will consist of approximately 24 single-user numerical machines equipped with high-resolution bit-mapped screens, a 32-bit central processor, and vector floating point hardware. It will also include several specialized server nodes and various peripheral devices including a gateway to the CSNET communications network linking the Nation's major computer science research centers.

The new facility will support a coherent research program in software systems, computer architecture, and quality numerical software, directed at creating a modern interactive environment for numerical computation.

University of Texas-Austin; Alfred G. Dale, James C. Browne, Donald Good, Elaine Rich and Abraham Silberschatz; ***An Experimental Computing Facility for the Design and Analysis of Reliable High-Performance Distributed Systems***; (MCS-8122039); $875,439; 12 mos.

This award will aid in the establishment of a major experimental facility that will incorporate mid-scale computers with large virtual addressing capabilities and powerful individual workstations linked over a high-speed local network. The facility, together with a professional support staff, will provide an environment for the development and experimental use of software for mechanical program and theorem proving, performance measurement and distributed computing. This integrated system design and analysis facility (SDAF) will:

1. Permit the consolidation of methods for mechanical program verification and performance analysis into an integrated approach to the analysis of distributed systems;
2. Support extensive experimental validation of formal analysis techniques;
3. Support novel applications of formal analysis methods to intelligent user-system interfaces and VLSI design.

University of Utah; Richard F. Riesenfeld and Lee A. Hollaar; *A Laboratory for Computer-Aided Design*; (MCS-8121750); $644,894; 12 mos.

This award will aid in the establishment of a major experimental facility to support a program of research on Computer-Aided Design (CAD) Systems. The facility will include powerful design workstations based on personal graphics-oriented machines. Included also will be a necessary expansion of general computing facilities to accommodate the expanded research effort. Several specialized 3-D output devices will provide a basis for testing the CAD techniques and tools developed as part of the research.

There are two main thrusts to the current efforts: Computer-aided 3-D shape design and Very Large Scale Integration (VLSI) design. The ALPHA-1 development project, at the heart of the first research thrust, is capable of supporting a wide range of CAD activities. Moving ALPHA-1 to a distributed environment will require research in operating systems and in workstation support and design. The investigators will also work on developing true 3-D display of surfaces and on Numerical-Control Milling Algorithms. Research in portability and software tools will lead to an enhanced software development environment; in database systems it will lead to an efficient uniform means for accessing, modifying, and sharing design data; and in multiprocessor and network operations it will allow the various tasks in the systems to be partitioned and run on processors best suited to their particular requirements. In integrated circuit design, the main emphasis will be on simulation systems improvement, on mapping techniques from high-level representations directly to design, on graphical representations of VLSI designs, and on the testing and diagnosis of integrated circuits.

University of Washington; Jerre D. Noe, Hellmut Golde, Edward D. Lazowska and G. T. Almes; ***A Functionally Integrated Environment for Distributed Computation***; (MCS-8004111 A02); $790,812; 12 mos.

This award will aid in the establishment of a major experimental research facility at the University of Washington. The investigators will design and build a powerful new kind of computing environment to facilitate communication and cooperation among researchers in the Department of Computer Science. It will be based on a "building sized" highly-parallel computer consisting of a functionally integrated collection of physically distributed personal computers cooperating through a local network. The primary focus of the research will be the development and exploration of programming methodologies, adapted to a distributed concurrent environment, which give each user access to the power and diversity of the entire system.

University of Wisconsin-Madison; Lawrence H. Landweber, Robert P. Cook, David Dewitt, and Raphael Finkel; *A Software-Partionable Multicomputer: A Testbed for Distributed Processing*; (MCS-8105904 A01 & A02); $1,064,967; 12 mos.

This award will aid in the establishment of a major experimental facility to support research in databases, distributed processing, operating systems, multicomputer architecture, and numerical analysis. The investigators will implement and study a computer architecture that will exploit recent advances in computer and communication technology. The facility will include a multicomputer, a small number of high-performance personal computers, and a support center. The multicomputer will implement the target research environment. The personal computers will serve as prototypes for program development research projects. The support center computers will provide program preparation, simulation, file, and device services.

The multicomputer will be a research tool and a research object for a variety of projects. The implementation of the architecture and kernelized operating system will itself be a major effort. Once a prototype system is constructed it will allow the multicomputer to be logically partitioned for independent simultaneous use by different researchers. A large number of projects can then be supported to examine research issues in the respective areas.

New Faculty Investigators in Experimental Research

University of Arizona; Timothy A. Budd; *Software Testing*; (MCS-8109547 A01); $61,158; 12 mos.

This grant will establish a research program designed to consider all aspects of software testing and validation from studies of the theory of testing to the design and construction of actual testing tools. Initially a major part of this research will be to continue on-going studies concerning the mutation analysis software testing methodology with particular emphasis on demonstrating the feasibility of using mutation analysis to test large production software components. A testing tool, written in RATFOR and designed to be portable to a large number of different machines, will be designed and constructed. A second part of this research will be to continue investigations in finding theoretical rationales for why and when methods that have been proposed will work, and to guide the search for new testing methods having theoretical justification.

University of Illinois-Urbana; Samuel N. Kamin; *The Pragmatics of Final Data Type Specifications* (*Computer Research*); (MCS-8110087 A01); $55,624; 12 mos.

A study of the pragmatics of a method of data type specification first presented by this investigator will be made. This method has the following important property, often said to characterize "abstractness" of a specification method: it is altogether free of "implementation bias." That is, it does not inherently favor any implementation over any other, the important point being that the programmer is freed to concentrate on real requirements. The development will be done in the stages.

1. A system for direct execution of specifications.
2. More ambitiously, a system for computer-assisted proofs of data type properties and of correctness of implementations.

In addition, the development of this system will provide practical experience in the use of the specification method in a large-scale programming project.

Purdue University; Dennis Gannon; *Algorithms and Architectures for Highly Parallel Solutions to Partial Differential Equations*; (MCS-8109512 A01); $55,680; 12 mos.

This project will develop and experimentally validate new algorithms and architectures for highly parallel solutions to PDE computations. The machines under consideration will be very large arrays of processors classified according to the associated interconnection scheme. Three basic problems are to be explored. First, a class of algorithms suitable for general problems on irregular domains will be redesigned to run on large MIMD machines. By exploiting the low processor utilization of several new and existing methods, it should be possible to provide substantial improvements in overall convergence rates without degradation of performance. Second, for limited processor applications, architectures will be considered that are appropriate for algorithms employing self adaptive techniques such as locally refined grids. Third, through a system of simulation and experiment the problems of programming large MIMD arrays will be confronted.

Columbia University; Yechiam Yemini; *Cooperative Distributed Computing in Computer Communication Networks*; (MCS-8110319 A01); $75,830; 12 mos.

The objective of this research is to study various issues arising in the design and implementation of distributed cooperative network software, including algorithm design for networks, performance analysis of network algorithms, language and system constructs for network computations, semantics of network computing and software tools for a network environment.

An experimental study of algorithm design and implementation in computer networks will be made, by concentrating on the following three classes of algorithms, possessing both practical and scientific significance: real-time topology-based adaptive network algorithms, distributed position-location algorithms, and decentralized real-time resource sharing algorithms in networks. A network-testbed to be used for experimentation will be developed. A study of language and system constructs, and software environment needed to support the difficult task of developing network-based systems will be made.

Computer Science Research Network (CSNET)

Rand Corporation; Anthony C. Hearn; *CSNET-Phonenet Operations and MMDF Development*; (MCS-8109321 A01); $96,822; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network (CSNET) for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and and access to remote databases.

The Rand Corporation will help to establish, improve, and maintain the Phonenet component of the network. Phonenet will allow CSNET users to interface with an integrated communication environment which can have several transmission channels. Consequently, sending a message to a local user, to user on a machine attached through a local, national or international packet network, or one on a machine accessible only through a telephone call involves the same effort and procedures. The degree to which users are affected by changes underlying channels is minimized. It is also intended that the need for multi-hop relaying will be transparent to the user. Thus, Phonenet will provide a message and file transfer capability to a wide class of users. Rand effort will concentrate on Phonenet users who are physically located in the western half of the United States.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

University of Delaware; David J. Farber; *CSNET-Phonenet Operations and MMDF Development*; (MCS-8109320 A02); $145,629; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network (CSNET) for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and access to remote databases.

Professor Farber will help to establish, improve, and maintain the Phonenet component of the network. Phonenet will allow CSNET users to interface with an integrated communication environment which can have several transmission channels. Consequently, sending a message to a local user, to a user on a machine attached through a local, national or international packet network, or to one on a machine accessible only through a telephone call involves the same effort and procedures. The degree to which users are affected by changes in underlying channels is minimized. It is also intended that the need for multi-hop relaying will be transparent to the user. Thus, Phonenet will provide a message and file transfer capability to a wide class of users. The University of Delaware effort will concentrate on Phonenet users who are physically located in the eastern half of the United States.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

Purdue University; Douglas E. Comer, Peter J. Denning and John T. Korb; *CSNET Protocol Development*; (MCS-8109322 A01 & A02); $112,277; 06 mos.

This project is part of a cooperative effort to establish a computer-based communication network (CSNET) among computer science research groups in universities, industry and government. The investigators will build a logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system. Communication services to be provided initially include message services, file transfer, and access to remote systems. Costs for use of the net will depend on the service utilized. The net will be open to all computer science research groups.

Purdue University will be the principal site for CSNET protocol development. It will be the responsibility of the investigators to develop and integrate the standard CSNET VAX operating system with appropriate subnet components. In particular, they will develop the software required to integrate Berkeley VAX UNIX with the CSNET protocol architecture (TCP/IP/X.25). Included are design and implementation of the corresponding interfaces and drivers. A goal is to enable Berkeley VAX UNIX systems to connect to Telenet when such systems run the CSNET protocol architecture.

Bolt, Beranek and Newman, Inc.; Richard D. Edmiston; *CSNET Coordination and Information Center*; (MCS-8202846); $336,635; 9 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks, including ARPANET, public packet networks and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and access to remote systems.

Bolt, Beranek and Newman, Inc. will assist the entire project by establishing a Coordination and Information Center (CIC). The CIC will act as the organization responsible for continuing network management with policies set by a Board of Directors chosen from among leaders in the computer science research community. Other functions to be provided by the CIC include bulk purchase of communication services, network accounting and billing, and dissemination of information on network access and services.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate net classes of research activities. The CIC is expected to be the focal point for continuing CSNET development and service so as to unite computer science researchers in the United States.

Department of Defense; Robert E. Kahn; *The CSNET Project*; (MCS-8116606 A01); $70,000; 02 mos.

This activity is part of the Coordinated Experimental Research (CER) Program in computer science that includes a major effort to develop distributed operating systems at the University of Washington and to establish a computer -based communication network (CSNET) through projects at the University of Delaware, Purdue University, and the University of Wisconsin. Since access related activities of research and development is essential to the success of the CER Program, it is important for all of these universities to be connected directly to ARPANET. In particular, the purpose of the present action is to reimburse the Department of Defense for computer equipment and operating cost associated with the use of ARPANET during FY 1981 and FY 1982.

A by-project of providing ARPANET services to these universities will be to stimulate computer science research through shared resources.

University of Wisconsin-Madison; Lawrence H. Landweber; *Service Host Functions and Technical Support of CSNET*; (MCS-8109318 A02); $445,866; 12 mos.

This project is part of a cooperative effort among computer scientists to establish a computer-based communication network for computer science research groups in universities, industry, and government. A logical network spanning several existing computer networks, including ARPANET, public packet networks, and Phonenet, a telephone-based relay system, will be established. Communication services to be provided initially include message services, file transfer, and access to remote databases. The University of Wisconsin-Madison will assist the entire project in several ways. First, it will establish three support groups: Technical Support Group, the Organizational Support Group, and Policy Support Group. Second, it will purchase or lease equipment as required by all components of the project. These support functions will be under the direction of Professor Lawrence H. Landweber.

In addition, Professor Marvin Solomon of the University of Wisconsin-Madison will establish a "Service Host" running the UNIX operating system on a VAX computer. This host will be a time sharing facility for the CSNET user community and will provide several classes of service, including mail-only and virtual-terminal service.

Objectives of CSNET are to help computer science research flourish through resource sharing and to stimulate new classes of research activities.

Small Business Innovation Research

Relational Technology, Inc.; Paul E. Butterworth ; *Table-Driven Code Generation Applied to a Database Management System*; (MCS-8260520); $29,550; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

This research program will investigate the feasibility of using table-driven code generation technology to build an efficient, portable query evaluator for a database management system. The specific topics to be studied include: table-driven code generators, intermediate forms for queries, and machine models for query evaluation. The goal is to automate the production of an efficient query evaluator for a new machine.

SYMANTEC; Ann E. Robinson ; *A Framework for Managing Dissimilar Data (Computer and Information Sciences)*; (MCS-8260719); $29,999; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

Today's information worker, who is becoming the key worker in the modern high-technology society, typically accesses a broad range of information of multiple types, stored both on computers and off-line. On-line information can include such forms as text, graphics, tables, databases, and digitized images and voice. Off-line information can include books, letters, maps, charts, and pictures on paper, film or magnetic media. Currently each type of information is stored in its own unique way, and different systems must be used to access and modify each type. This research project is aimed at establishing a computational technology that will facilitate the management in a uniform way of these diverse types of information. This project will create a computational environment in which diverse types of data are coordinated in a central framework and one human/machine interface is used for all data types.

PRB Associates, Inc.; Willaim R. Bass ; *Determination of the Requirements for Use of Three-Dimensional Displays in Ultrasonic Imaging*; (MCS-8260495); $29,836; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

The scope of this effort shall be to determine the data collection and signal processing requirements necessary to support the presentation of clinical diagnostic information on a three-dimensional, non-holographic, display system utilizing ultrasonic sounding as the data source. Pursuant to this effort, state-of-the-art signal processing techniques and technologies normally associated with militarized signal processing shall be evaluated for applicability in the areas of ultrasonic data processing. Further, functional software modules necessary to perform data manipulation/processing and display updates shall be identified and delineated. Additionally, the man-machine interface shall be refined to provide delineation of display requirements best suited for a clinical environment. The culmination of this effort shall be the determination of the feasibility of developing a clinical analysis device which can be used as a diagnostic tool that offers an alternative to radiological and surgical procedures.

C. Abaci, Inc.; Edward L. Battiste ; *Robust Scientific Software for Micro-Computer Usage*; (MCS-8260282); $30,000; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

The use of micro-computers is migrating from specific to general purpose. Micro-computer technology is evolving rapidly, in hardware and in software areas. No significant software effort is taking place so as to achieve the goals of (1) providing robust software kernels and (2) writing, and applying pressure toward the acceptance of, standards for languages and hardware which will allow positive evolution of usage of micro-computers. The advances in software of the last decade, in large scale computing endeavors, are not transferring to micro-computer users.

The feasibility of producing scientific software adequate for use by the (new) micro-computing audience will be investigated. During this investigation the problems which elevate difficulty in, and cost of, such production, as they relate to hardware and software distributions by manufacturers will be isolated. The availability of such software could result in remarkable productivity gains. The publication of resultant reports will aid manufacturers of new environments in serving the user set with responsibility.

School of Experimental Ecology; John D. Garcia ; *Development of an Electronic Signature Lock for Data Security*; (MCS-8260703); $30,000; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

It is postulated that persons inputting data through a digital device will have a unique pattern of time delays between characters within a standardized message that will make them differentiable from other persons inputting the same message. This is their electronic signature. If the pattern is unique and not too variable for a given person then an application of statistical discrimination theory can be used to distinguish authorized users from unauthorized users. Phase I of the project involves performing an experiment on 60 persons to determine if effective statistical discrimination is possible by these means. "Effective" means having a very small probability of giving access to properly authorized persons. Phase I will show which, if any, algorithms exist for discriminating between unauthorized and authorized persons. If this approach to data security is not technically feasible, it will be shown that this is the case. Therefore, the results will be useful whatever the outcome of the experiment. No special hardware need be built in this phase although a standard microcomputer with input/output devices will have to be used to gather and analyze the data.

Phase II will involve the construction of a prototype electronic signature lock using state of the art computer technology together with the development of an optimum discrimination algorithm. Phase III is the mass production and marketing of the Electronic Signature Lock.

Tartan Laboratories Incorporated; John R. Nestor; *Extensions to Attribute Grammars (Computer Languages)*; (MCS-8260633); $30,000; 6 mos.

This Phase I award is made under the 1982 Small Business Innovation Research Program Solicitation.

Historically, the development of formal definition techniques has lead to insight into various classes of algorithms and has often provided a basis for the automatic generation of software. Automatically generated software is both less expensive to create and less likely to contain errors.

This project will investigate extensions to one formal definition technique, attribute grammars. Attribute grammars have been used for formal definitions of programming language semantics and have provided a basis for systems that automatically generate semantic analyzers. Attribute grammars have however proved to be too weak to specify some important parts of semantic analysis and to specify other closely related applications. The extensions considered will permit attribute grammars to specify transformations and to deal with directed graphs. The research includes identification of specific extensions, theoretical and practical analysis of these extensions, and implementation of prototype automatic generation tools. Anticipated results include both the theoretical benefits of improved formal definitions and the practical benefits of using automatic generation systems to lower the cost and improve the quality of software.

END

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